VOLUME XXXII NUMBER 8

THE
JOURNAL OF GEOLOGY

November-December 1924

MORAINES OF THE ST. LAWRENCE VALLEY

FRANK BURSLEY TAYLOR
Fort Wayne, Indiana

ABSTRACT

Two marginal moraines, the Albion and the Oswego, lying near Lake Ontario and belonging to the recessional series of western New York, were traced with substantial continuity from previously determined points near Rochester to the vicinity of Watertown, and to points farther northeast, where they were lost in the Adirondack forest. Four later moraines of the same series, passing near Watertown, Philadelphia, Gouverneur, and Dekalb, respectively, were followed with some few breaks from the region of Watertown northeast toward the Champlain–St. Lawrence watershed, which passes close to the village of Churubusco. Three of them were followed across the divide and southward along the Lake Champlain slope to the hills northwest of Plattsburg. Part of a still later moraine was found on the Champlain slope.

These moraines mark successive re-advance positions of the ice front as it retreated from the basin of Lake Ontario and down the St. Lawrence Valley. They cover the entire duration of Glacial Lake Iroquois and a considerable part of the duration of Niagara Falls. Thus, five new moraines are added to the previously known list which was already significantly long.

INTRODUCTION

One of the most significant characteristics of the deposits of the last or Wisconsin ice sheet is its moraines of recession. In these moraines, the ice sheet made a wonderfully delicate record of certain minor oscillations which were superimposed upon the general climatic amelioration. They record these oscillations as perfectly as a self-recording barometer marks the changes in the pressure of the air. The cause of the oscillations has not yet been explained, but

it seems certain that every added fact bearing on their distribution and relations will help to bring the explanation nearer.

From the meridian of Buffalo, New York, westward over the region of the Great Lakes to the Dakotas, the mapping of the recessional moraines was substantially complete more than ten years ago,[1] and the mapping of the moraines in the southwestern peninsula of Ontario west of the same meridian had been carried nearly as far.[2] The moraines of the Buffalo-Niagara district were mapped by the writer in 1910–13,[3] and some of them were traced eastward to the vicinity of Rochester and Canadaigua in 1917.[4] Mr. Frank Leverett had already traced the Albion moraine into Rochester, and two or three others to the vicinity of Batavia in 1891.[5] Up to 1920, however, no continuous tracing farther east or northeast had been accomplished. It is the object of the present paper to give an account of recent studies of certain recessional moraines which have been found in the St. Lawrence Valley, in the region between the Genesee River and the northern part of Lake Champlain, lying mainly along the western and northern border of the Adirondacks.

The first studies were made on the plain lying between the river and the mountains and stretching northeast from Watertown. But after the work of the first summer, it became apparent that the interval between Rochester and Watertown ought to be included, for the results attained in the northern area, whatever they might be, would otherwise remain isolated and unconnected with the well-

[1] Monographs of the U.S. Geological Survey: *The Illinois Glacial Lobe* (1899), No. 38, by Frank Leverett. *Glacial formations and Drainage Features of the Erie and Ohio Basins* (1902), No. 41, by Frank Leverett. *The Pleistocene of Indiana and Michigan and the History of the Great Lakes* (1915), No. 53, by Frank Leverett and Frank B. Taylor. Also publications of the Geological Surveys of Wisconsin, Iowa, Minnesota, and North and South Dakota, and many individual contributions of various authors in current scientific journals, and proceedings of societies. (See bibliography in Monograph 53 referred to above.)

[2] Frank B. Taylor, "The Moraine Systems of Southwestern Ontario," *Trans. Canadian Inst.*, Vol. X, Part 1 (1913).

[3] "The Niagara Folio," *U.S. Geol. Survey Folio 190*, 1913.

[4] Report on field work done in 1917 not yet published.

[5] "Correlation of Moraines with Raised Beaches of Lake Erie," *Amer. Jour. Sci.*, 3d Ser., Vol. XLIII (1892). Also *U.S. Geol. Survey Mon. 41*, pp. 672–709, referred to above.

determined moraine systems farther west. So, in the second year, the scope of the studies was broadened to include this area.

For the most part, the field studies described in this paper were made possible by grants in 1920 and 1921 from the Research Fund of the American Association for the Advancement of Science, and grateful acknowledgment of this aid is here made. More field work, however, seemed necessary, and four weeks were given to this work in the summer of 1923 at private expense.

EARLIER STUDIES OF MORAINES IN THIS AREA

In other parts of New York east of Rochester, short sections of moraine, few longer than 5 miles, have been mapped at various earlier times by other investigators. Charles R. Dryer mapped several moraine fragments in the vicinity of Rochester and Victor, and also in the western Finger Lakes region.[1] R. S. Tarr mapped the glacial features in the region around Watkins and Ithaca in great detail, but his studies were in a very complex area, and individual moraines were not identified for long distances.[2] Between 1900 and 1916, a few longer sections were mapped by the writer in connection with work on the Housatonic, Taconic, and Mettawee quadrangles, which lie along the eastern border of the state east of the Hudson River. But within the area covered by the present studies, earlier descriptions are relatively few, and most of them are of rather recent date. In connection with his extensive studies of glacial drainage and lakes in New York, Professor H. L. Fairchild has noted the presence of moraines or of moraine-like deposits at many places.[3] But the parts mapped by him have remained unconnected, continuous tracing not having been carried far enough to show with certainty the configuration of the ice front for any considerable distance at any one of its several positions.

Around Covey Hill in Quebec, and southward along the Lake Champlain slope, Gilbert, Woodworth, Fairchild, and others,

[1] "Glacial Geology of the Irondequoit Region," *Amer. Geol.*, Vol. V (1890). Also "Finger Lakes Region of Western New York," *Bull. G.S.A.*, Vol. XV (1904).

[2] "The Watkins Glen–Catatonk Folio," *U.S. Geol. Survey Folio 169*, 1909.

[3] Chiefly in bulletins of the New York State Museum. Also in *American Geologist*, *Bulletin of the Geological Society of America*, and *Proceedings of Rochester Academy of Science;* more particular references later.

including the present writer, long ago recognized as indispensable the presence of an ice barrier along the east side of the heavily scoured "Flat Rock" area.[1] But the front of the ice in that interval was so strongly scoured by a great river that very little morainic material recognizable as such was left, and no definite moraine was mapped in that position. No continuous tracing of ice borders by moraines or other related features was accomplished by any of the earlier investigators.

THE MORAINES IN BRIEF

In order to establish sure connections and relations between the moraines in the northern part of the state and the well-determined systems extending west from Rochester, it seemed necessary to trace at least one or two moraines continuously from well-established points near Rochester to the vicinity of Watertown. The Albion moraine was the latest which gave promise of extending through to the northern field. By following it continuously, and by exploring the country lying between it and the lake, any younger moraines that might be found in this interval would also aid in establishing a closer connection.

In 1912 the Carlton moraine had been found in fine form close to the lake shore in Orleans and northwestern Monroe counties, but later (1917) it was found to be cut away east of Rochester, and so appeared to offer little help for the purpose in hand. East of Rochester, however, another moraine was found in 1921 holding a position between the Albion and the Carlton. This moraine passes through Oswego and Mexico and is here called the Oswego moraine. These two members of the recessional series were traced with substantial continuity to the vicinity of Watertown, and they establish the desired connection with the northern moraines in a very satisfactory manner. Both of these moraines were traced northeast from Watertown to points where they were lost in the Adirondack forest.

[1] Unpublished field notes by Dr. G. K. Gilbert. Gilbert's notes are referred to frequently by Professor J. B. Woodworth in his reports in *New York State Museum Bulls. 83, 84,* 1905. Professor H. L. Fairchild's work is contained in *New York State Museum Bulls. 209–10,* 1919. A few observations were made by the writer in this area in the autumn of 1893, but have never been published.

SKETCH MAP OF THE MORAINES OF TH

STORMONT
DUNDAS
GRENVILLE
GRENVILLE S.
ST. LAWRENCE RIVER
Prescott
Ogdensburg
Potsdam
Massena
Malone
Plattsburg
Elizabethtown
ADIRONDACK
MOUNTAINS
Lake Pleasant
Lake George
FULTON
MONTGOMERY
SCHENECTADY
Johnstown
Gloversville
Amsterdam
Schenectady
Saratoga Springs
Ballston Spa
Cherry Valley
Morristown
Chateaugay
Rouses Point
Tupper Lake
Indian R.
Hudson R.
Mohawk R.
Sacandaga R.
Canada Creek
Lake George
Glens Falls
Fort Ann
Crown Pt.
Minerville
Port Henry
Keeseville
Au Sable Forks
Lake Placid
Saranac Lake
Raquette Lake
Newton Falls
Canton
Potsdam
Regis Falls
Brasher Falls
Hammond
Waddington
Morristown
Brockville
Montreal
Ogdensburg
Massena
Malone
Plattsburg
Elizabethtown
Lake George
Schenectady
Johnstown
Amsterdam
Gloversville
Saratoga Springs
Ballston Spa
Cherry Valley
Morristown
Chateaugay
Rouses Point
Tupper Lake
Indian R.
Hudson R.
Mohawk R.
Sacandaga R.
Canada Creek
Lake George
Glens Falls
Fort Ann
Crown Pt.
Minerville
Port Henry
Keeseville
Au Sable Forks
Lake Placid
Saranac Lake
Raquette Lake
Newton Falls
Canton
Potsdam
Regis Falls
Brasher Falls
Hammond
Waddington

On a line running from Watertown to Dekalb Junction, four more younger moraines of the same recessional series were found and are here designated by the names of the principal places through or near to which they pass, namely, the Watertown, Philadelphia, Gouverneur, and Dekalb moraines.

In the rough forested region northeast of Watertown and east and northeast of Gouverneur, none of the moraines were traced with perfect continuity. Not that continuous tracing cannot be accomplished, but that the time and means available for the work were not sufficient for that result.

On present knowledge, the Philadelphia moraine is a short fragment for which no certain connection was found either to the northeast or the southwest. With a few interpolated gaps, the other three—the Watertown, the Gouverneur, and the Dekalb—were traced through to the divide near Churubusco, and southeast along the Champlain slope to the hills northwest of Plattsburg. Fragments of another moraine were found at Cannon Corners, near Altona and near West Chazy on the Champlain slope. This is evidently the next younger moraine than the Dekalb.

Plate I is a sketch map showing the general distribution of the moraines described. The beach of Glacial Lake Iroquois lies on the same slope, and introduced serious but very interesting difficulties in the way of tracing the moraines. Figure 1 shows the relation between the Iroquois and upper marine beaches and the moraines. It is diagrammatic and omits many minor details of both the beaches and the moraines. The beaches follow Fairchild in the main.[1] Figures for altitudes on the moraines are, of course, only approximate.

SOME DETAILS OF THE MORAINES

General characteristics.—The recessional moraines of western and northern New York are, for the most part, perceptibly weaker in their development than members of the same series in most of the states farther west, notably in the southwestern peninsula of Ontario, in Ohio, Indiana, and Michigan.

The difficulties of tracing moraines in the area studied were also considerably increased by the hilly or moderately mountainous

[1] *New York State Museum Bulls. 209–10*, 1919, Plate IV.

character of the country. Where the moraines are weak and their average relief is under 20 feet or even 15 for miles at a stretch, as is often the case in this region, and when the local relief upon which the moraines are laid down is several times greater than that of

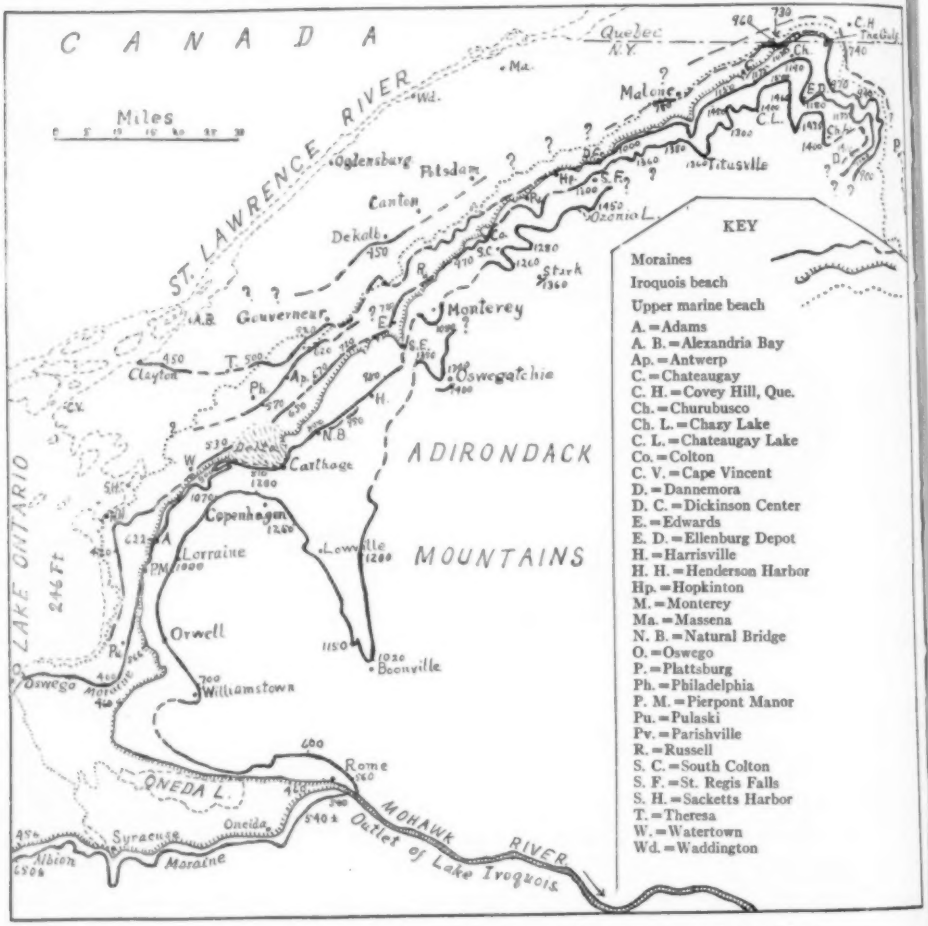


FIG. 1.—The moraines in relation to the Iroquois and upper marine beaches, Oswego to Plattsburg, with altitudes.

the moraines themselves, the recognition and tracing of the moraines sometimes becomes very difficult. Nor could they be followed successfully through the forest.

Still another obstacle arose from the fact that a considerable part of the moraines studied were water laid, i.e., they were laid down at and under the edge of the ice where the ice front was standing in still water of greater or less depth. Water-laid moraines are smoother and less rugged than the ordinary land-laid type. Where this effect is pronounced, the recognition of the moraines may become very difficult. When they are faintly developed, water-laid moraines have also notably fewer associated features which help in their recognition—fewer kames and outwash deposits, no border drainage channels, fewer bowlders, a smoother surface, and less relief generally. On account of the limited space available only a few of the salient features of each moraine can be described here.

THE ALBION MORAINE

The Pinnacle Hills interlobate ridge.—In order to make the picture of the Albion moraine in the Rochester region more complete, some of the characteristics of the Pinnacle Hills and of the Albion moraine from Rochester to Henrietta are briefly mentioned, although most of the field work on these parts was done in 1917. For 8 or 10 miles west of Rochester, the Albion moraine is in most places a rather smooth till ridge with a southward or frontal relief of 10 to 20 or sometimes 30 feet. Its average altitude is slightly under 600 feet above sea-level, its highest parts reaching a little above 620 feet. East of the Genesee, it extends as a low ridge for half a mile where it merges into a remarkable cluster of kames in the old part of Mount Hope Cemetery. Beyond this the higher range of the Pinnacle Hills extends east-northeast about 4 miles. With its steep slopes north and south and its uneven crestline, the range is a striking object in the landscape (Fig. 2, *A* and *B*). The highest knob, Pinnacle Hill, attains an altitude of about 750 feet above sea-level. The eastern end of the range is strongly overridden with heavy bowlder clay. The rest is largely composed of gravel and sand, some of it cross-bedded as in kames, other parts in stratified beds sloping mostly toward the south. The stronger ice

action and supply of sediment was from the north, but both sides of the range show ice-contact slopes, thus making the range a typical interlobate deposit. It is rather narrow at its base, with a double phase through most of its length, but averages four or five times the height of the simple frontal moraine to the west and south. Agreeably with this interpretation, the kames in the cemetery are the coarse deposit of a stream which flowed swiftly westward out of the interlobate angle.[1] The interlobate origin of the Pinnacle Hills is

A

FIG. 2.—*A*, Part of Pinnacle Range, next west of "The Pinnacle." Looking north on South Clinton Street, at a distance of one-half a mile.

clearly indicated by their distribution and form. The range is narrow and nearly straight, showing that it was closely pressed between the two glacial lobes. Even where it shows double lines,

[1] Professor H. L. Fairchild's memoir (*Proc. Rochester Acad. of Science*, Vol. VI, No. 5 [1923]) entitled "The Pinnacle Hills or the Rochester Kame-Moraine," was received when the present paper was nearly finished. The many photographs of excavations, especially of *old* excavations, showing composition and structural features no longer to be seen, are particularly valuable, from a historical as well as from a scientific point of view. For the most part, the text gives a clear account of the structures and features shown, but presents no discussion of the interlobate character of the formation, the only reference to this idea being contained in a four-line footnote on p. 165. Nor is there any reference to the Henrietta section of the Albion moraine which marks the western side of the Irondequoit sublobe.

these are set close together. These characters are plainly in contrast with some other nearby kame areas which are clearly not interlobate, for example, the Mendon Hills 9 miles south of Rochester, and the Junius kames east of West Junius. These areas are both normal developments of kame-moraine deposits—heavy morainic knolls and ridges including many kames with knob and kettle forms, and surrounding larger basins which hold ponds. The two tiny ponds which formerly existed in the narrow trough of the Pinnacle

B

FIG. 2.—*B*, The Pinnacle, the highest point in the range of the Pinnacle Hills. Looking north from a point near South Clinton Street, half a mile south of the range.

Hills correspond to the larger ponds in the more roomy spaces of the other areas.

The Irondequoit sublobe.—Close east of the cemetery, a smooth till ridge springs from the west end of the Pinnacle Range and runs directly south to Henrietta (see Fig. 3). It has a peculiar scalloped form with convex curves toward the west and sharper angles to the east. The curves seem to hang on small drumlinoids, one at each angle. East of Henrietta, the moraine, as a low but very distinct till ridge, turns northeast and north to a small bunch of drumlinoids south of Edgewood. Here it turns east, but after crossing a branch of Allen Creek, is less distinct, because it rests against the base of

higher ground to the south. Nevertheless, its wavy surface and occasional small basins make it clearly traceable.

East of Pittsford a considerable embayment opens southward into the hills. Into this the ice must have pushed several miles, its apex resting probably about at Railroad Mills. Scarcely any

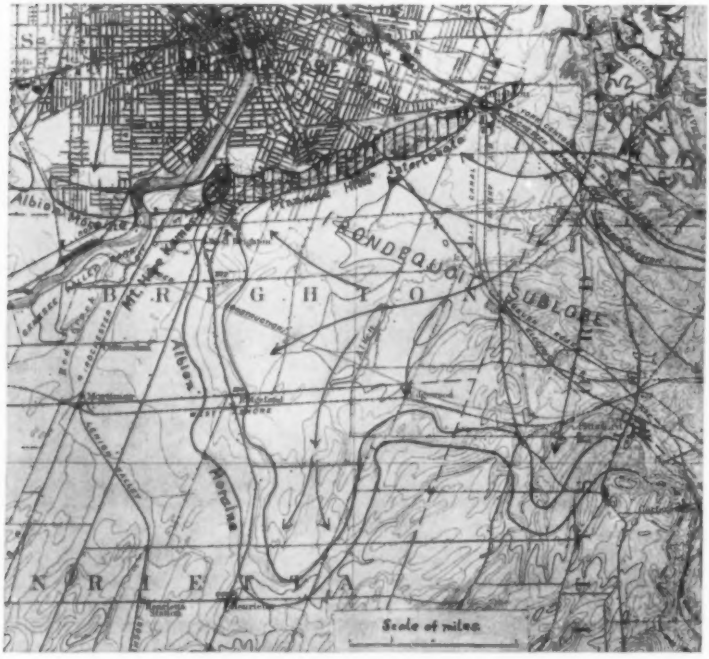


FIG. 3.—The Albion moraine, south of Rochester, New York, and the Pinnacle Hills interlobate ridge.

evidence of a distinctive moraine was found in this embayment. But the front of the ice rested against steep slopes, a situation very unfavorable for the making of well-defined moraines. The front of the ice appears to have lapped around the end of the hills northeast of Bushnell Basin, passing a mile north of Egypt. North of Thomas Creek and about 4 miles east of Fairport, the moraine

reappears in better form and in greater strength, and it continues in this character for many miles. At first its course is northeast, but south of West Walworth it turns gradually to the east, passing a mile north of Walworth. This angle marks the eastern limit of the Irondequoit sublobe. The movement of the marginal part of the ice at the time of the Albion moraine was directly up the axis of the Irondequoit depression. This relation strongly favored the development of the sublobe.

In two of his papers, Professor Fairchild shows a direct continuation of the Albion moraine east of the Irondequoit depression. In one he shows a moraine in Wayne County east of Rochester more than 3 miles wide and covering the whole space between the Iroquois beach and the northern edge of the pronounced drumlin area to the south.[1] In a later paper he shows a very irregular belt of moraine extending eastward from the Irondequoit depression, roughly on the line of the Pinnacle Hills produced, and reaching to a point south of Ontario village.[2] The later paper therefore includes the area of the first, but in neither is the moraine belt shown extending far enough south to include the Albion moraine as recently mapped by the writer.

In 1923 the ground extending eastward from the Irondequoit depression, including the area mapped by Professor Fairchild and also the broad re-entrant of the ice front in southwestern Wayne County, was carefully reviewed. There are scattered morainic knolls in that belt, mingled with veneered rock knolls and fragmental drumlinoids. But morainic knolls of the same character and in increasing numbers are scattered southward for 4 or 5 miles down to the more pronounced front line of the Albion moraine, as mapped by the writer in 1921 and 1923. The features appear to be due to a broadening of the Albion moraine in somewhat broken form. The writer was unable to distinguish a separate recessional moraine on the course shown by Professor Fairchild.

The contours on Professor Fairchild's map (Fig. 1 referred to above) show very clearly the low ridge which runs south from Mount

[1] *New York State Museum Bull. 111*, 1907, Plate XV.

[2] *Proc. of the Rochester Acad. of Science*, Vol. VI (1919), Plate II.

Hope Cemetery to Henrietta. Concerning this ridge and the Pinnacle Hills, Mr. Leverett says:

> The Pinnacle Hills ridge is thought by Fairchild to be a marginal moraine, but to the writer it appears more like a spur extending back from the inner border of the moraine. A low till ridge, which leads from its western end southward toward Ridgeland, is thought to mark the continuation of the Albion moraine. As this lies beyond the field allotted for investigation, its course was not traced farther than Ridgeland.[1]

The reason for the interlobate character of the deposit becomes plain only when the ridge extending south to Henrietta is recognized as the western boundary of a subordinate ice lobe spreading from the Irondequoit Valley.

The Cayuga ice tongue.—The place where the moraine crosses the river 3 miles east of Phelps and its extension past West Junius are very clearly defined. The West Junius kames evidently belong to the Albion moraine, for they stand in its line, and sandy outwash covers 4 or 5 square miles of the plain to the south. From the kames to Seneca Falls the moraine is unique for this region. It is built on a smooth plain with no drumlins or other relief features to modify its form. It is a simple, water-laid, low, ridge of bowlder clay, and is well shown by the contours on the Geneva topographic sheet.[2] It controls the local drainage completely, as does also its fainter extension southeast from Seneca Falls to Canoga. Thus, the ice pushed a sharp tongue into the Cayuga Lake basin, the apex resting several miles south of Canoga. The moraine is well developed among the knolls a mile or two south of Port Byron, Weedsport, and Jordan, and between Jordan and Elbridge is nearly 2 miles wide. The ice pressed against the escarpment all the way from Cayuga Lake to Oneida, probably most severely at a point between Syracuse and Weedsport. The higher parts on the moraine a few miles east of Elbridge seem to mark a crest, the altitude declining westward to Cayuga Lake and eastward to Rome. On Cayuga Lake 1 mile south of Canoga, the altitude is about 470 feet, east of Elbridge 650–700 feet, at apex east of Rome 560 feet, and south of Rome 500 feet.

[1] *U.S. Geol. Survey Mon. 41*, 1902, p. 702.

[2] Part of this ridge, extending 4 miles west from Seneca Falls, is shown as a moraine on one of Professor Fairchild's maps. *New York State Museum Bull. 111*, 1907, Plate XIII.

The Oneida sublobe.—From the crest east of Elbridge, a line drawn northeast over the west end of Oneida Lake marks approximately the base of a very pronounced sublobe, projecting east over 50 miles to a point 6 miles east of Rome. Along the escarpment from Cayuga Lake to Oneida, the moraine is broken and hard to follow. But near Sherrill, 4 miles east of Oneida, it turns abruptly north along the face of a gentle westward slope, and in 15 miles curves gradually around to an easterly course south of Rome. Freed from the complication of drumlin and rock relief larger than its own, the moraine stands forth from Sherrill to Stanwix as a well-defined ridge (Fig. 4). Eastward it grows narrow and lower, and ends on the bank of the Mohawk a mile east of Stanwix, where it was cut off by the great outlet river of Glacial Lake Iroquois.

FIG. 4.—The Albion moraine, 3 miles north of Sherrill. Looking west toward its front.

The Rutland re-entrant.—A small blunt sublobe at Williamstown is clearly defined by a short esker and kames associated with the moraine, and by an outwash plain extending down Fish Creek to Camden. The moraine grows stronger north of Salmon River, and, at Orwell, North Boylston, and northward, deep border drainage channels cut across the normal drainage courses (Fig. 5). At the same time, as it approaches the high re-entrant, the moraine rises more rapidly, and attains its steepest gradient near the top of the hill. From slightly below 700 feet at Williamstown, it rises to about 850 at Orwell; 950 near North Boylston; 1,000 near Winona; 1,040 near Lorraine; 1,080 near Whitesville; 1,190, 2 miles east of Middle Road Church (see Fig. 6); and 1,250 east of Copenhagen. The rate is 15–20 feet per mile in the steeper parts. This rise is due mainly

FIG. 5.—Albion moraine, 2 miles north of Whitesville. Looking south. Morainic knolls in middle-ground.

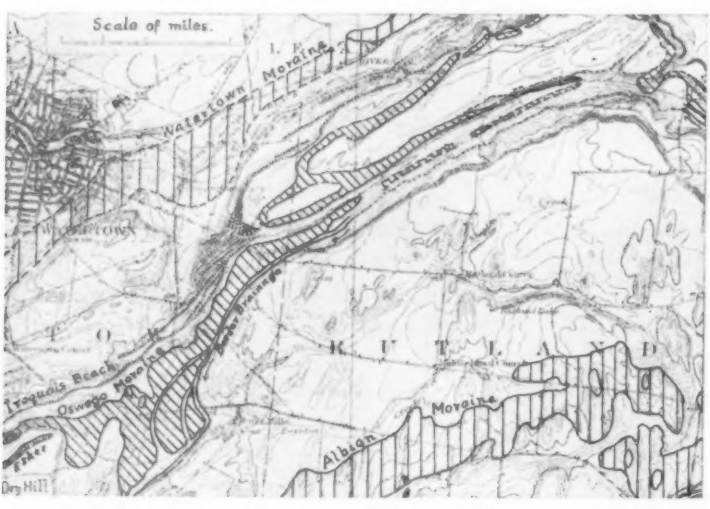


FIG. 6.—Features east of Watertown. Parts of the Albion, Oswego, and Watertown moraines and the Iroquois beach. Shows the sharp tongue of the Oswego moraine in Rutland Hollow.

to an effect like that of a nunatak; Orwell is well down on the lea side, where the ice margin was low, while Copenhagen is on the front or stoss side, where the ice rode up to its highest level.

The Black River lobe.—At this stage a sharp ice lobe projected 35 miles south in Black River Valley nearly to Boonville. Its west side, being nearly on the isobasic line, shows only slight descent. For 3 or 4 miles northwest of Lowville, the moraine in part forms a well-defined parapet ridge along the edge of the rock terrace, and the same effect is well displayed on the double rock terrace between House Creek and Mill Creek. One mile northeast of Talcottville, the moraine forms a very pronounced obstruction across a small valley, with altitude of 1,150 feet. The extreme point of the lobe is about 2 miles north of Boonville with altitude of about 1,020 feet. This lobe was crowded so closely on its east side by very heavy outwash deposits set in narrow lake waters that its upper limit is not well displayed. Beyond 20 miles of forest, morainic deposits of a tongue having its apex near Oswegatchie in the valley of Little River seem from their altitude—about 1,350 feet—to belong to the Albion line, but this relation is not yet established.

THE OSWEGO MORAINE

Relation to the Carlton moraine.—The Carlton moraine is very prominent west of Manitou Beach,[1] but only a short fragment of it, extending 5 miles east from Ninemile Point, occurs east of Rochester. It is a well-formed single ridge, rather prominent for a water-laid moraine. A mile or so south of it east of Ninemile Point, another morraine is represented by a belt of low irregular knolls, which is continuous eastward with the Oswego moraine, where it is developed in much better form.

Moraine on drumlins: Wolcott to Mexico.—From about 4 miles west of Wolcott to 4 miles east of Mexico—a distance of 50 miles on the line of the moraine—the Oswego moraine is almost perfectly uniform in its strength and in all other characteristics. It is a weak, water-laid feature, and throughout the whole interval was deposited upon a strong drumlin topography. The morainic knolls are mostly low and inconspicuous, but they form a belt commonly

[1] "Niagara Folio," *U.S. Geol. Survey Folio 190*, 1913, p. 10.

about 1 mile wide, whose topographic expression is seen, where observed closely, to be strikingly unlike that of the drumlins. It forms a slightly wavy, irregular surface, and its upper edge marks the place where the front of the depositing ice rested against the smooth forms of the drumlins. The upper limit is very sharply marked in many places, both on the drumlin ridges and in the intervening hollows. Northwest of Wolcott, east of Oswego and east of Mexico, the line is particularly sharp. The altitude of this moraine is 330–40 feet a few miles east of Irondequoit Bay, near Wolcott 375 feet, west of Mexico 400 feet, and 4 miles east of Mexico about 410 feet.[1]

FIG. 7.—Bowlder pavement below Iroquois beach (smooth ridge at skyline). Location, 3 miles south of Adams. Bowlders are residue of Oswego moraine.

Emergence from Lake Iroquois.—At the angle east of Mexico, the moraine turns sharply north, becomes ill defined and soon begins to rise at a higher rate than the Iroquois beach. Its indefiniteness increases progressively toward Sandy Creek, Mannsville, and Pierpont Manor. North of the last-named place and south of Sandy Creek, an unusually heavy bowlder pavement lies at the base of the beach and suggests the presence of the moraine strongly

[1] In *New York State Museum Bull. 111*, Plate VI, Professor Fairchild shows about 4 miles of this moraine extending east from Oswego, but shows no extension of it in either direction. In the field its upper limit is very sharply defined, but is somewhat higher and more even in altitude than shown by him.

modified by wave action (Fig. 7). At a point about 2 miles north of Adams the moraine emerges into the area above the beach. Between Sandy Creek and this point it rises from 490 or 500 feet to about 660 feet, a rise of 170 feet in 14 miles—a rate of over 12 feet per mile. At Adams the altitude of the Iroquois beach is 622 feet.

The Rutland ice tongue.—East and southeast of Watertown the Oswego moraine is of much interest. The edge of the ice rested on the upper part of "The Mountain" where it overlooks the valley of Black River to the north and the city of Watertown to the west. The deep depression of Rutland Hollow cuts through the northern part, leaving the main mountain to the south with a rather high narrow ridge on the north.

In Rutland Hollow, the Oswego moraine is a unique feature. The tongue of ice which pushed into this narrow trough is, relative to its width, the longest, most sharply pointed tongue found in this region. Figure 6 shows its ground plan. It shows a further peculiarity in that it projects directly back in the reverse direction to that in which the main ice stream was moving. The moraine crosses the west end of the hill north of the hollow as a very pronounced block moraine, being made up almost entirely of large blocks of limestone, transported only a fraction of a mile from outcropping ledges on the north face of the hill. The tongue was about 4 miles long and tapered to a sharp point. Toward its apex the moraine on the north side of the hollow becomes a narrow, smooth, rounded ridge much resembling an esker, but where deeply cut on the road north from Rutland Center, is seen to be bowldery till, typical moraine material. The moraines on both sides of the valley for a mile or so east of East Watertown are marked by a great number of blocks. On the south side a large river, which was the outlet of a contemporary lake in the Black River Valley, flowed past the front of the ice. It washed away most of the finer material and left a moraine of the "bear den" type. Figure 8 is a view south from the block moraine across the river channel in the foreground. A small tongue pushed into the east end of the hollow through a narrow ravine and made a small fan-shaped moraine three-fourths of a mile east of the apex of the main tongue. Rutland Hollow deserves to be a classic locality for the study of these features.

High ridge moraine near Natural Bridge.—For 4 or 5 miles west from Natural Bridge, the Oswego moraine takes on an unusual degree of relief, being in some places 40 to 50 feet high with steep slopes, the steeper to the south. It seems probable that its front was in effect heightened and steepened to some extent by border drainage. Its height and narrowness gives it some resemblance to a large massive esker. But while it is gravelly in some parts, it is composed mainly of bowlder clay and includes a few kames and one or two short esker ridges leading up to its north side.

FIG. 8.—Oswego moraine. View southeast from block moraine in Rutland Hollow. Depression in foreground is channel of border river.

Harrisville bowldery moraine.—For 5 or 6 miles southwest and northeast of Harrisville, the Oswego moraine is distinguished for the great number of crystalline bowlders, many very large ones, which enter into its make-up. Morainic knolls and also the bowlders are well displayed on the road south from Pitcairn to Bacon.

The tongue moraine at Monterey.—Beyond a few miles of forest, through which the course of the moraine is interpolated, morainic deposits on the slopes around Monterey appear to belong to the Oswego line. Morainic knolls in strong relief and carrying a great concentration of bowlders form the apex of the tongue around the Upper De Grasse School 2 miles south of Monterey. High-level

outwash deposits are prominent west of the school. Finely formed tongue moraines 4 miles southeast and east of South Colton, and also heavy bowldery morainic deposits at the northeast side of Ozonia Lake are believed to belong to the Oswego stage.

THE WATERTOWN MORAINE

The moraine of this name is poorly developed in the vicinity of Watertown, mainly because it is water laid, and also because to the southwest and south it is in some places buried under lake clay.

Bowldery moraine and crag-tail.—West and north of Black River the Watertown moraine is well developed in limited areas.

FIG. 9.—Watertown moraine eroded by the modern river. Looking northeast, 1 mile west of Black River.

Figure 9 shows a part a mile west where the modern river has cut into the moraine, showing how heavily it is charged with bowlders. Fairchild marks the whole tract north of the sand plains and between Black River and Leraysville as moraine.[1] But much of it appears to the writer to be a sort of crag-tail—blocks and bowlders moved a little way from their parent ledges, many of them not carried forward far enough to be incorporated into the frontal moraine.

East Antwerp and beyond.—Passing by a few fragments near Deferiet, and poorly developed deposits west and north of North

[1] *New York State Museum Bull. 145*, 1910, Plate XLIV.

Wilna and Woods Mill, a pronounced stretch of this moraine advantageously situated for observation begins near East Antwerp and extends northeast to Balmat Corners. A considerable part is of the kame-moraine type, and the relief of the knolls is commonly 20–30 or 40 feet.

Beyond this the Watertown moraine passes into a rough forested country, and its identity on present knowledge is doubtful. But a fine stretch of moraine, with a number of large kames associated extends northeast, from near Edwards toward Russell, and is tentatively correlated with the Watertown. But the place of emergence from Lake Iroquois remains to be discovered.

St. Regis Falls to Dannemora.—The strong block and bowlder moraine at Harper School probably belongs to the Watertown. Less than 2 miles northeast of St. Regis Falls a great kame-moraine forms a complete barrier across the valley of the east branch of St. Regis River and diverts the stream to the west. From its altitude, about 1,300 feet, while the moraine at Ozonia Lake is 1,450 feet, it seems fairly certain that the former is the next later member after that at the lake. The latter being 7 miles southwest of the former, the normal difference in altitude would be at least 200 feet. It is therefore assumed tentatively that the moraine at St. Regis Falls belongs to the Watertown line. Then, beyond a forested gap of 7 miles, a fine moraine of a small tongue a mile south of Skerry begins a line of morainic deposits that was followed with almost perfect continuity through many small valley tongues and re-entrants to Great Chazy River. Among the finer tongues were those reaching up Salmon River to Titusville, one projecting into the north end of Lower Chateaugay Lake, and west and south of Ellenburg Center. It is well developed also at Halfway House, 6 miles south of Ellenburg Depot, on Great Chazy River 2 miles east of Chazy Lake, and also southeast of Jerico.[1]

THE PHILADELPHIA MORAINE

Moderate-sized kames and low morainic knolls form a line extending from Philadelphia to Antwerp, passing about 2 miles east of both places. From Antwerp to Sprague ville, the line is repre-

[1] *New York State Museum Bull. 84*, 1905, Plate XXIX.

sented only by low bowldery till knolls among rock bosses. At Spragueville it seems continued in large kames that extend more than a mile to the northeast. But these kames are only a mile from the Gouverneur moraine, which stands just back of them and 100 feet lower. As no continuation to the east or northeast was found, it seems possible that the kames at Spragueville belong to the Gouverneur moraine, but their higher altitude makes this uncertain. The status of the Philadelphia moraine is therefore in doubt. If it extends on toward the northeast, it seems probable that it is

FIG. 10.—Gouverneur moraine. Kame-moraine, 1 mile north of Bentley Corners. Looking north.

overlapped by the Gouverneur moraine. This, for the present, will be held as a tentative conclusion.

THE GOUVERNEUR MORAINE

Gouverneur to Clayton.—A well-defined moraine, including a number of kames, extends southwest from Gouverneur to Keene, 5 miles distant. Continuing, the line turns toward the west and becomes broken, the easily recognizable features being farther apart. A fine large kame of this line lies a mile north of Bentley Corners (Fig. 10). Then a long gap with no notable morainic features reaches to a prominent bunch of kames 2 miles north of

Lafargeville, and, across a shorter gap, the line continues to more kames at Clayton on the St. Lawrence River. Professor Fairchild maps these kames as partly morainic and includes other areas of wavy moraine-like topography which proved to be rather deep lake or marine clay.[1] To the east and northeast from Gouverneur no certain extension of this moraine was found.

Churubusco to Dickinson Center.—In the absence of continuous tracing or other sure identification with the established moraines farther southwest, the stretch between Churubusco and Dickinson Center will be regarded tentatively as the northeastward extension of the Gouverneur moraine.

The front of the moraine is about three-fourths of a mile south of Churubusco, the village itself being situated on the main ridge. In contrast with the Watertown moraine which, in this part of the area, shows that the ice pushed a tongue into each of the Adirondack valleys, the Gouverneur moraine, lying on the slope below the mouths of these valleys, runs in a nearly straight line to Dickinson Center, a distance of nearly 40 miles. The only place where it deviates notably is in the valley of Salmon River south of Malone, where the ice thrust a sharp tongue up the valley about 4 miles.

The country is open, and the moraine, though not strong in the eastern part and in the parts approaching the Salmon River Valley, is readily traceable through the whole interval. It passes a mile or more south of Chateaugay and is particularly fine on the west side of the river, where drainage from a temporary lake to the south cut deep channels through it to the west. Beyond Salmon River the moraine grows stronger and the border drainage increases in volume, until, toward Dickinson Center, as shown in Figure 11, both become prominent features. This stretch of moraine, with its strong border drainage channel and its relations to Lake Iroquois, is in many respects the most clearly developed and the most interesting moraine found in this field.

The passing of the Oswego moraine under the level of Lake Iroquois near Adams was described above. A better example of this relation occurs near Dickinson Center or Nicholville, where the Gouverneur moraine passes under the same lake-level. The rela-

[1] *New York State Museum Bull. 145*, 1910, Plate XLVI.

tions are much simpler and more evident above lake-level, but more difficult below than they are for the Oswego moraine. It is interesting to note that less than a mile south of Churubusco the moraine has an altitude of about 1,190 feet, while 2 miles north of the same place the Iroquois beach, as shown by Professor Fairchild, is 1,020 feet, thus leaving an interval of 170 feet between them; whereas, at Dickinson Center or a few miles farther west the two come to the same level and the moraine passes under. The moraine and the beach gradually converge toward the southwest, the moraine

FIG. 11.—Gouverneur moraine, looking north. Depression in foreground is channel of border drainage. The heavy ridge at skyline is the moraine. Locality, 1 mile south and 1½ miles east of East Dickinson. The Iroquois beach is on far side of ridge.

descending about 5 feet per mile more rapidly than the beach, so that at a point about south of Bangor the Iroquois beach begins to encroach upon the lower rear part of the moraine, and from that on the beach rises relatively higher and higher on the moraine, until in the east part of Dickinson Center very little of the moraine protrudes above the beach. For about 3 miles west of this place, no morainic features were seen above the beach, but, from south of Days Mill to a point south of Nicholville, low morainic knolls were seen. Beyond this in several places, the beach has an outer bar, a bar outside of the

regular beach line, situated apparently on a knoll that was barely submerged. These knolls appeared to belong to the moraine.

The continuation of the moraine westward under the level of the beach was not satisfactorily traced out and awaits more detailed study.

On the Champlain slope.—Just east of Churubusco this moraine crosses the St. Lawrence–Champlain divide and turns south. It shows fair strength to the little valley north of Ellenburg Center where its knolls are well developed. Thence it runs in broken form along the rugged slope to the east and southeast. Part of this moraine extending southwest from Big Hill was mapped by Woodworth many years ago.[1]

THE DEKALB MORAINE

The western section.—In the western part of the field, this moraine is now known only from a fragment 6 or 7 miles long extending east and west south of Dekalb and Dekalb Junction. The part south of the Junction occupies a peculiar position, for it runs 3 miles or more along the crest of a ridge of gneiss without descending into the depression south of it. But east of Dekalb it descends across the trough, leaving a few fine gravelly knolls to mark its path, and continues southwest along a rocky escarpment which overlooks the Oswegatchie River. Rock knolls are mingled with the drift knolls of the moraine, but the latter are of good size, some 30–40 feet high.

The eastern section.—After a gap of 50 miles, a moraine occupying the same relation to the Gouverneur moraine and presumably belonging to the Dekalb appears near the International boundary 3 miles north of Churubusco. The section is hardly 3 miles long, but it is a prominent feature, being in places 30–40 feet high. It is made up of two or three parallel ridges separated by channels resembling those of border drainage. The crest at Liberty Pole School is about 60 feet below the Iroquois beach less than a mile to the south, and 230 feet above the upper marine beach 2 miles to the north.

On the Champlain slope.—South of the boundary this moraine reappears near Woods School, and with increasing strength and

[1] *New York State Museum Bull. 84*, 1905, Plate XXII.

definiteness extends straight south to Ellenburg Depot. For more than a mile south of the station, the deposit takes on large development as a kame-moraine. Its highest point is over 100 feet above its base. Figure 12 is a view northward along its top. This deposit and the great kame-moraine of St. Regis Falls are good evidences of a movement of re-advance on the part of the ice, both being sand and gravel deposits made in a small basin in front of the ice at the preceding backstep and later carried forward and built into the features now seen.

FIG. 12.—Dekalb moraine. Looking north on high kame-moraine, 1 mile south of Ellenburg Depot.

This moraine continues eastward in fair strength and is easily followed to a point about 3 miles south of Altona. Beyond this it is, so far as seen, poorly developed at most places, until within 5 or 6 miles of Cadyville in the Saranac Valley. A peculiarity at three or four places north of Cadyville is seen where the front of the moraine is sharply defined against detached knolls of rock which are separated from the main hill by deep rock-walled channels cut, apparently, by a border drainage river.

CANNON CORNERS MORAINE

For a mile or more north of Cannon Corners fragmental bowldery till deposits, much modified by river scour, appear to mark the place of a moraine. They lie along the lower edge of the heavy scour-

way shown by Professor Fairchild[1] and a little above the strong upper marine beaches. It seems certain that these deposits mark the place of the moraine next younger than the Dekalb. Normally, this moraine would descend gradually southward close along the lower border of the heavily scoured "Flat Rock" area, but would pass under the upper marine beach. Three miles northwest of West Chazy, Cobblestone Hill is a prominent feature, and is apparently a morainic knoll largely modified, first by river scour and later by wave action. It appears to be a part of the Cannon Corners moraine. Northwest of Cannon Corners the altitude on the moraine is 740–60 feet. Cobblestone Hill fills the whole interval between 600 and 700 feet, the north end standing as a narrow ridge slightly above 700 feet. Here, then, the Cannon Corners moraine has passed barely under the level of the marine waters. Another morainic deposit 2–4 miles east of Altona probably belongs to the same line, but its upper part has been cut away by wave action. This fragment and Cobblestone Hill are shown by Woodworth on his map of the surface geology of the Mooers quandrangle.[2]

THE DRUMLINIZED ST. LAWRENCE PLAIN

On the plain between the river and the moraines shown on Plate I, especially in the northeastern part of the area, a thorough search for moraines was made with only negative results. The whole region from the Canadian boundary north of Malone to a point somewhat beyond Ogdensburg toward the southwest is a "drumlinized" country. The surface is covered with a thick coating of bowlder clay which has been shaped into drumlin-like forms, and yet scarcely any of them are even roughly perfect. In some parts the till is intensely bowldery, and in certain places close below some of the lower marine beaches, the bowlders cover the surface so thickly that they form a true bowlder pavement. Chadwick found the same kind of surface forms in the Canton quadrangle.[3]

A marked peculiarity of the drumlinoids of this region is seen in the way they are arranged. In some cases a number of them stand end to end so as to form a chain. Partly on account of the

[1] *New York State Museum Bulls. 209–10*, 1910, Plate V.

[2] *New York State Museum Bull. 84*, 1905. Fairchild describes Cobblestone Hill in *Bulls. 209–10*, 1919, pp. 51–52.

[3] *New York State Museum Bulls. 217–18*, 1920, pp. 49–50.

imperfection of their drumlinoid forms, some of these chains simulate moraines. But their axes always trend with the direction of ice movement, and they lack other specific characteristics of moraines. Southwest of Ogdensburg the drumlinoids are fewer, and a little farther on they disappear altogether. Toward Lake Ontario the drift grows thin over nearly horizontal Paleozoic rocks.

TWO CORRELATIVE MORAINES IN CANADA

Toward the close of field work the first year, a few days were spent in search of moraines in Canada. On the plain between Prescott and Ottawa, the same drumlinized forms prevail. A few gravelly ridges trending with the direction of ice movement were found, but no moraines were seen. Two short sections of moraine were found, one 10 or 12 miles west of Perth, and one at Tweed, the latter particularly strong and accompanied by strong border drainage. The correlative relations of these to those on the south side of the St. Lawrence were not determined.

CONCLUSION

These field studies have an intimate bearing upon several problems which are more or less closely related.

1. The number of the recessional moraines is increased by five, increasing proportionately their weight as evidences of uniform periodic oscillation in the amelioration of glacial climate.

2. The results of these studies make sure that in the near future the recessional moraine series will be traced continuously around the Adirondacks, and also through the Mohawk Valley to the Hudson, thus connecting the western system with that of New England.

3. Correlations of measured sections of the Niagara gorge with moraines of this series give early promise of yielding a time ratio of exceptional value, and one that will be applicable, with but slight modifications, to the whole area of the Wisconsin drift.

4. The relation of the recessional moraines to the "varve" clays which Dr. Antevs has studied in the Connecticut Valley, following the remarkable results of Baron DeGeer in Sweden, presents a problem of great interest. But whether his results can be harmonized with those derived from Niagara and the recessional moraines seems at present doubtful.

SOME GEOCHEMICAL RELATIONS OF GROUND WATER AND ASSOCIATED NATURAL GAS IN THE LANCE FORMATION, MONTANA[1]

B. COLEMAN RENICK
U.S. Geological Survey, Washington, D.C.

ABSTRACT

A study of the waters and gases from the Lance (Tertiary?) formation in a number of gas-bearing artesian wells in Rosebud County, Montana, shows that methane derived from carbonaceous material in the Lance beds reduces the sulphate in the water, forming hydrogen sulphate and bicarbonate or carbonate. Nitrogen is relatively high in all the gases and at a few places is so high as to prevent combustion, reaching a maximum of 96 per cent. Most of the gases, however, are combustible. The high nitrogen content is suggestive of the presence of the rare gas, helium, but the character of the rocks precludes the occurrence of helium in commercial amounts.

INTRODUCTION

Natural gas is contained in many ground waters, but the chemical reactions between different types of gas and different types of ground water have been little studied by geologists and geochemists. Mills and Wells[2] have discussed some of the physical phenomena of natural gas and ground water in connection with their study of the waters in the Appalachian oil and gas fields, and Rogers,[3] in his report on the Sunset-Midway field of California, mentions some physico-chemical relations of gas and ground water. More recently, Jones, Yant, and Buxton[4] have suggested that the gas content of ground water may be of assistance in discovering oil and gas pools. These writers do not carefully correlate the geologic source of the gas with its chemical character, nor do they give any

[1] Published by permission of the director, U.S. Geological Survey, Washington, D.C.

[2] R. Van A. Mills and R. C. Wells, "The Evaporation and Concentration of Waters Associated with Petroleum and Natural Gas," *U.S. Geol. Surv. Bull. 693* (1919), pp. 77–89.

[3] G. S. Rogers, "The Sunset-Midway Oil Field, California: Part II, Geochemical Relations of the Oil, Gas, and Water," *U.S. Geol. Surv. Prof. Paper 117*, 1919.

[4] G. W. Jones, W. P. Yant, and E. P. Buxton, "Gaseous Content of Ground Waters as an Aid to the Petroleum and Natural Gas Prospector," *U.S. Bur. Mines Serial No. 2553*, December, 1923.

account of the chemical character of the associated ground water, though both of these considerations would be helpful in interpreting the gas analyses which they cite. The literature on the subject of ground water and associated natural gas is exceptionally meager as to both the geologic and the chemical aspects. In the course of an investigation of the geology and ground-water resources of an area in Rosebud County, Montana, for the United States Geological Survey,[1] a number of gas-bearing artesian wells were observed, and it is the purpose of this paper to set forth and interpret the geochemical data obtained from studying these wells.

ACKNOWLEDGMENTS

Grateful acknowledgments are due to Messrs. R. C. Wells, O. E. Meinzer, and K. C. Heald, of the United States Geological Survey, for helpful discussions and critical reading of the manuscript, and to Mr. H. B. Riffenburg, for the analysis of the water samples which were made in connection with official ground water investigations of this survey. Mr. G. W. Jones, of the Pittsburgh experiment station of the United States Bureau of Mines, has kindly furnished the analyses of the gas samples which he has made use of in his own researches. The illustrations were prepared by the United States Geological Survey under the direction of Mr. Martin Solem.

GEOLOGY[2]

The areal and structural geology of the area under consideration is shown in Figure 1. The Claggett, Judith River, and Bearpaw formations of the Montana group (Upper Cretaceous), named in ascending order, crop out in the southern nose of the Porcupine dome which is the pronounced structural feature in the northwest corner of the map (Fig. 1). These formations are approximately 425, 300, and 950 feet thick, respectively, but only the upper part of the Claggett is shown on the map. These beds of the Montana group are unimportant so far as the present paper is concerned, and so far

[1] B. Coleman Renick, "Geology and Ground Water Resources of Central and Southern Rosebud County, Montana," *U.S. Geol. Surv. Water-Supply Paper* (in preparation).

[2] Nomenclature approved by the Committee of Geologic Names, U.S. Geological Survey.

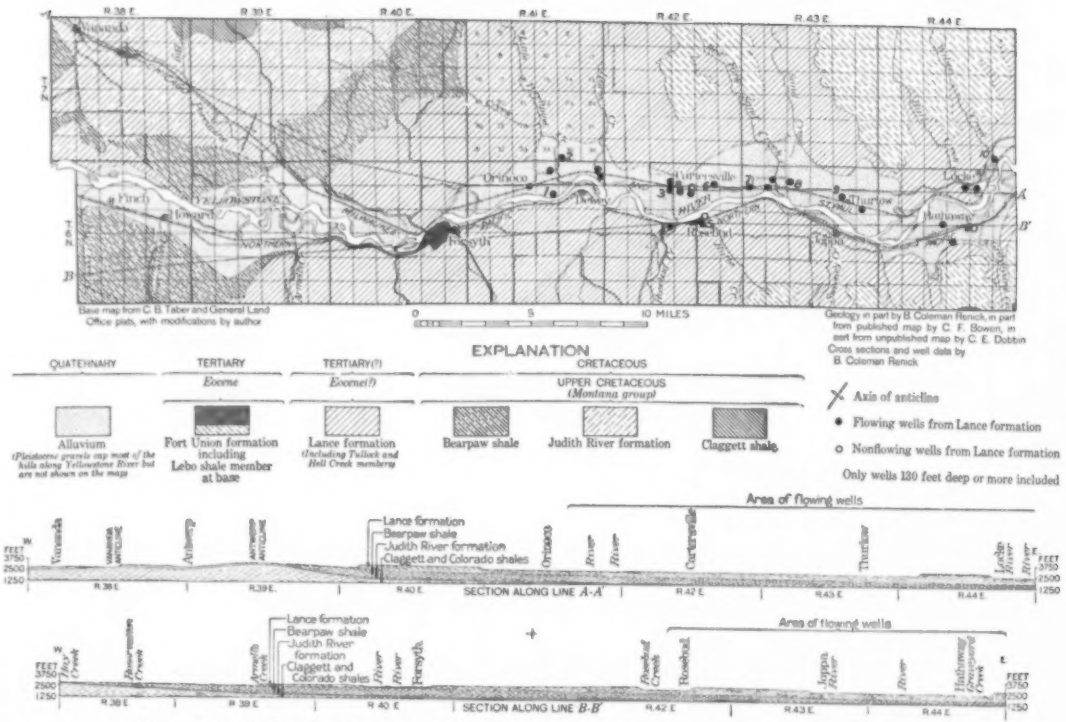


FIG. 1.—Geologic map and cross-sections along Yellowstone River, Rosebud County, Montana

as the lithologic character of this group is concerned it will be sufficient merely to mention that except for a small amount of sand in the Claggett and a sandstone at the top and bottom of the Judith River formation the entire Montana group is represented by shale. The stratigraphy of the Montana group in this region has been reviewed by Bowen.[1] In eastern Montana the equivalent of this dark-colored Bearpaw shale is included in the Pierre shale, which is overlaid by the Fox Hills sandstone, on which rests the Lance formation. In the area considered in this paper, the Bearpaw shale is overlaid, without observable stratigraphic hiatus, by the fresh-water Lance formation, of Tertiary (?) age. The sandstone in the lower part of the beds here assigned to the Lance formation may correspond to the Fox Hills sandstone to the east, as shown in Figure 2. The Lance formation is here about 925 feet thick and is divided into an upper and a lower member.[2] The lower member, known as the Hell Creek member, is about 675 feet thick, and is made up of yellow sandstone and yellow shale, with a heavy sandstone at the base and heavy lenticular sandstone beds distributed throughout. The shale is calcareous in places, and a few carbonaceous bands

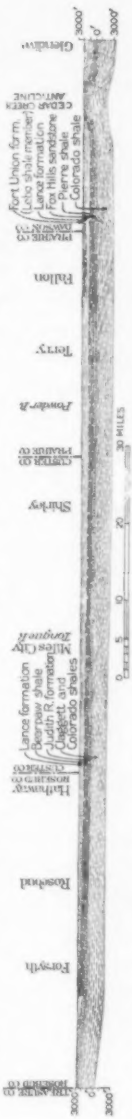


FIG. 2.—Geologic cross-section showing structure of the artesian basin along the Yellowstone River (Rosebud, Custer, Prairie, and Dawson counties, Mont.).

[1] C. F. Bowen, "Stratigraphy of the Montana Group, with Special Reference to the Position and Age of the Judith River Formation in North-Central Montana," *U.S. Geol. Surv. Prof. Paper 90* (1914), pp. 95–151; "Gradations from Continental to Marine Conditions of Deposition in Central Montana during the Eagle and Judith River Epochs," *ibid.*, No. 125 (1919), pp. 11–21.

[2] G. S. Rogers and Wallace Lee, "Geology of the Tullock Creek Coal Field, Montana," *U.S. Geol. Surv. Bull. 749* (1923), p. 19; C. E. Dobbin and N. W. Bass, "Geology of the Forsyth Coal Field, Rosebud, Treasure, and Bighorn Counties, Montana," *U S. Geol. Surv. Bull.* (in preparation).

have been noted. The upper or Tullock member of the Lance consists of yellow sandstone and shale, and differs from the lower member in that it contains a number of thin coal beds and carbonaceous seams. This member is approximately 250 feet thick and includes at the top a thin persistent sandstone which throughout this area gives rise to a well-developed rim rock.

The Fort Union formation is not directly concerned with the problem considered in this paper, but it crops out in the bluffs a short distance from the river (Fig. 1). It is divisible into a lower so-called somber member, made up of dark-gray to black shale and sandstone, and an upper member of light-colored sandstone, shale, and coal. The lower member, known as the Lebo shale,[1] averages about 175 feet in thickness, and the upper member, which is the great coal-bearing group of rocks in this region, approximates 1,680 feet.[2]

The portion of Rosebud County that lies along Yellowstone River is on the western flank of a large syncline, the eastern edge of which is terminated by the Cedar Creek anticline near Glendive, Montana, and the center of which is near Miles City, Montana (Fig. 2). The regional dip in Rosebud County is therefore eastward; the maximum is 10° and the minimum a few feet to the mile.

Silt, sand, and gravel make up the flood-plain deposits of Yellowstone River and its tributaries, and the bluffs adjacent to the river are capped with Pleistocene terrace gravel. The Pleistocene gravel is not shown on the map (Fig. 1).

THE ARTESIAN BASIN

Flowing wells have been obtained along the flood plain of Yellowstone River from a point a few miles east of Forsyth approximately to Fallon and also along several of the tributaries of the Yellow-

[1] R. W. Stone and W. R. Calvert, "Stratigraphic Relations of the Livingston Formation of Montana," *Econ. Geol.*, Vol. V (1910), pp. 752 ff.; L. H. Woolsey, R. W. Richards, and C. T. Lupton, "The Bull Mountain Coal Field, Musselshell and Yellowstone Counties, Montana," *U.S. Geol. Surv. Bull. 647* (1917), pp. 24–27; G. S. Rogers and Wallace Lee, "Geology of the Tullock Creek Coal Field, Montana," *ibid.*, No. 749 (1923), pp. 35–39.

[2] C. E. Dobbin and N. W. Bass, "Geology of the Forsyth Coal Field, Rosebud, Treasure, and Bighorn Counties, Montana," *U.S. Geol. Surv. Bull.* (in preparation).

stone, including Tongue River, Powder River, and O'Fallon Creek (Fig. 2). These artesian wells are from 150 to about 900 feet deep and obtain their water from the sandstones of the Lance formation.

In Rosebud County, the area here under consideration, the wells obtain their water almost entirely from the sandstone beds within the Hell Creek member of the Lance, but more especially from the heavy sandstone at the base of that member. These aquifers, together with the impervious Lance shales above and the Bearpaw or Pierre shales below, and the structural conditions as described in a preceding paragraph, furnish all the requirements for artesian flow.

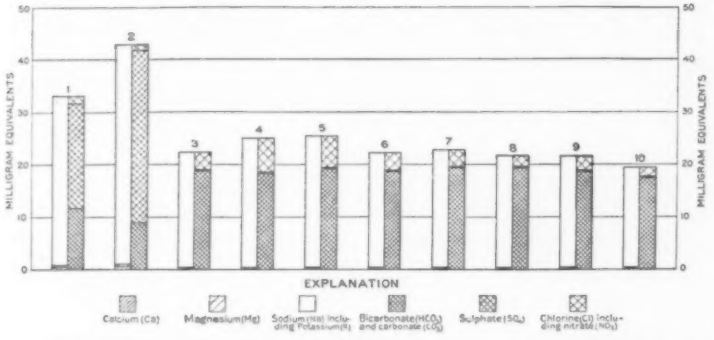


FIG. 3.—Graphic representation of analyses of waters from some gas-bearing artesian wells along the Yellowstone River, Rosebud County, Montana.

The yield of these artesian wells ranges from a fraction of a gallon to 25 gallons a minute, depending on various modifying factors, including topography, dip of the strata, rock texture, and depth and age of the well. The maximum observed head was 18 feet. The altitude of the outcrop of the basal sandstone of the Lance formation is approximately 300 feet above that of the mouth of the well where this head was observed, and the sandstone was reached in the well at about 500 feet below the surface. As the well is about 14 miles from the outcrop, this means a hydraulic gradient of about 20 feet to the mile. When one of these wells is drilled, the usual procedure is to set a 4-inch casing in the first suitable stratum below the alluvium. This prevents the so-called "surface" or alluvium

water from entering the well. Within this 4-inch casing is inserted a $2\frac{1}{2}$-inch casing which extends to whatever depth may be necessary. Care was exercised in collecting the samples discussed in succeeding paragraphs, and it is believed that they are typical of the artesian waters in Rosebud County.

CHEMICAL CHARACTER OF THE ARTESIAN WATERS

The results of the ten analyses of water samples are shown in Table I, and are represented graphically, according to reacting values or milligram equivalents,[1,2] in Figure 3. The method of representation has been adopted after Collins.[3]

Samples 1 and 2 are more highly mineralized than samples 3–10. Also, the first two waters are high in the sulphate radicle, whereas in the other eight waters the sulphate radicle is negligible. Samples 3–10 are essentially sodium bicarbonate waters, a class that cannot be regarded as common. In addition to the high sulphate radicle in samples 1 and 2, these waters also contain considerable amounts of bicarbonate. The sodium radicle is especially high in all ten samples, but the calcium and magnesium radicles are negligible in all.

The waters high in sodium bicarbonate are soft and characteristic of the deep wells,[4] which obtain their waters from the Lance

[1] Herman Stabler, "The Mineral Analysis of Water for Industrial Purposes and Its Interpretation by the Engineer," *Eng. News*, Vol. LX (1908), p. 356; Chase Palmer, "The Geochemical Interpretation of Water Analyses," *U.S. Geol. Surv. Bull. 479*, 1911; G. S. Rogers, "The Interpretation of Water Analyses by the Geologist," *Econ. Geol.*, Vol. XII (1917), pp. 56–88.

[2] The milligram equivalents are calculated in the following manner:

$$\text{Combining weight of radicle} = \frac{\text{Atomic weight or sum of the atomic weights}}{\text{Valence of the radicle}}$$

then

$$\text{Number of milligram equivalents} = \frac{\text{Parts per million}}{\text{Combining weight of the radicle}}$$

In Fig. 3, 1-mg. equivalent = 23 parts per million of Na, 39 K, 20 Ca, 12 Mg, 61 HCO_3, 30 CO_3, 48 SO_4, and 35 Cl.

[3] W. D. Collins, "Graphic Representation of Water Analyses," *Ind. and Eng. Chemistry*, Vol. XV (1923), p. 394.

[4] The term "deep wells" is here used to designate wells that obtain their water from pervious aquifers below the alluvium. Their depth is of the magnitude of a few hundreds of feet; that of the wells which obtain water from the alluvium is a few tens of feet.

TABLE I

TABLE I

ANALYSES OF WATERS FROM GAS-BEARING ARTESIAN WELLS, ROSEBUD COUNTY, MONTANA
(Analyzed by H. B. Riffenburg. Parts per million)

	1	2	3	4	5	6	7	8	9	10
Silica (SiO_2)	12	12	11	14	16	16	15	11	17	11
Iron (Fe)	.20	Trace	.27	.27	.20	.30	.20	.20	.30	.20
Calcium (Ca)	6.0	13	3.6	2.8	2.6	4.0	4.0	3.6	3.6	4.0
Magnesium (Mg)	4.2	4.4	1.7	3.1	3.0	3.1	1.9	2.3	2.5	2.9
Sodium and potassium (Na+K)	750	964	504	575	576	500	516	488	490	433
Carbonate radicle (CO_3)	24	14	36	0	43	12	9.6	24	7.2	72
Bicarbonate radicle (HCO_3)	669	527	1,074	1,115	1,127	1,147	1,169	1,086	1,139	927
Sulphate radicle (SO_4)	979	1,594	.7	2.3	1.0	2.3	.8	3.0	2.1	3.3
Chloride radicle (Cl)	48	34	120	242	204	116	118	92	96	64
Nitrate radicle (NO_3)	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	.67
Hydrogen sulphide (H_2S)	5.5	(*b*)	(*a*)	(*a*)	(*b*)	(*a*)	(*a*)	(*b*)	(*a*)	(*a*)
Total dissolved solids at 180° C	2,102	2,916	1,202	1,442	1,403	1,250	1,268	1,182	1,220	1,081
Total hardness as $CaCO_3$ (calculated)	32	50	16	20	19	23	18	18	19	22
Date of collection	Oct. 6, 1923	Sept. 8, 1923	Oct. 1, 1923	Oct. 3, 1923	Oct. 3, 1923	Oct. 1, 1923	Oct. 1, 1923	Oct. 3, 1923	Oct. 3, 1923	Aug. 8, 1923

a) Not determined.
b) Samples collected for H_2S determination but no cadmium sulphide observed in bottle.
1. Depth—243 feet; location—SW. ¼, Sec. 10, T.6 N., R.41 E.
2. Depth—255 feet; location—SW. ¼, Sec. 35, T.7 N., R.41 E.
3. Depth—260± feet; location—NE. ¼, Sec. 9, T.6 N., R.42 E.
4. Depth—130 feet; location—NE. ¼ of SE. ¼, Sec. 16, T.6 N., R.42 E.
5. Depth—402 feet; location—SW. ¼, Sec. 14, T.6 N., R.42 E.
6. Depth—502 feet; location—SE. ¼, Sec. 2, T.6 N., R.42 E.
7. Depth—590± feet; location—SE. ¼, Sec. 6, T.6 N., R.43 E.
8. Depth—486 feet; location—SW. ¼, Sec. 4, T.6 N., R.43 E.
9. Depth—525 feet; location—NW. ¼, Sec. 11, T.6 N R.43 E.
10. Depth—434 feet; location—SW. ¼, Sec. 36, T.7 N., R.44 E.

TABLE II*

ANALYSES OF GASES FROM GAS-BEARING ARTESIAN WELLS, ROSEBUD COUNTY, MONTANA
(Analyzed by G. W. Jones. Recorded in nearest percentage)

	1	2	3	4	5	6	7	8	9	10
Temperature °F	52	53	54	53	52	54	55	55	55	53
Cubic Centimeter of Gas at 24° C. and 745-mm. Hg (Pressure) per Liter of H_2O (Water)	29.3	33.2	45.9	55.6	46.6	61.9	62.1	60.9	64.2	44.4
Methane (CH_4)	0	0	58	60	58	66	66	60	60	37
Ethane (C_2H_6)	0	0	0	0	0	0	0	0	0	0
Carbon dioxide (CO_2)	3	2	4	2	5	3	3	3	3	4
Oxygen (O_2)	1	3	2	0	0	6	0	0	0	0
Nitrogen (N_2)	96	95	36	38	37	30	31	37	37	59
Total	100	100	100	100	100	100	100	100	100	100

* Locations of numbers 1–10 same as in Table I.

formation. The water from the alluvium is very different, being almost invariably high in calcium and magnesium, and correspondingly lower in sodium, which means that the waters from the alluvium are hard. Certain chemical changes which take place in these waters with increasing depth are discussed in another paper.[1]

CHEMICAL CHARACTER OF THE GASES

At each of the ten wells examined two samples of the gas-bearing waters were collected in a 1-pint magnesium citrate bottle with a porcelain stopper and rubber gasket, about 1 cubic centimeter of free air-space being left to allow for changes in temperature. The bottles were filled rapidly, the stopper was quickly clamped down, and the temperature of the water at the time of collection was recorded.

The apparatus ordinarily used in the laboratory for gas analysis is intricate and requires expert technique to manipulate properly; realizing this, Messrs. Jones, Yant, and Buxton,[2] of the United States Bureau of Mines, have designed and described a simple field apparatus, which does not require an experienced gas chemist to manipulate, for determining the gas content of ground waters.

The analyses of the gases contained in these artesian waters are represented in Table II, which shows that samples 1 and 2 are different from samples 3–8, in that the first two contain no methane and are especially high in nitrogen.

For a hydrogen sulphide determination some of the water is collected in a separate bottle containing a small amount of cadmium chloride which fixes the sulphur of the hydrogen sulphide as cadmium sulphide. This method of a separate collection of water for this determination is necessary, for, otherwise, the readily oxidizable hydrogen sulphide would be converted to sulphate by the time it reached the laboratory. Samples for determination of hydrogen sulphide were collected at wells 1, 2, and 5, 8, but the sample from well 1 was the only one that gave off a readily detectable amount of hydrogen sulphide (Table I). The samples from

[1] B. Coleman Renick, "Base Exchange in Ground Water as Illustrated in Montana," *U.S. Geol. Surv. Water-Supply Paper 520-D* (in press).

[2] G. W. Jones, W. P. Yant, and E. P. Buxton, *op. cit.*

wells 5 and 8 are typical of wells 3–10, and it is certain that no observable amount of hydrogen sulphide is being evolved from these latter eight wells.

The higher the percentage of C_nH_{2n+2} and C_nH_{2n}, the higher the heating value of a gas, and, conversely, the higher the percentage of nitrogen and carbon dioxide the lower the heating value.

TABLE III

ANALYSES SHOWING VARIOUS TYPES OF NATURAL GAS*

	1	2	3	4	5	6	7
Methane (CH_4)	86.7	96.5	67.6	6.6	66.2	23.6	51.3
Ethane (C_2H_6)	9.5	.0	31.3	91.1	1.0	69.7	10.4
Carbon dioxide (CO_2)	1.7	1.4	.0	.0	30.4	2.5	.1
Nitrogen (N_2)†	2.1	2.1	1.1	2.3	2.4	1.3	38.2
Hydrogen sulphide (H_2S)	.....	.....	.....	.....	.....	2.9	.....
Oxygen (O_2)	.0	.0	.0	.0	.0	.0	.0
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

* By Bureau of Mines. Cited by G. S. Rogers, *U.S. Geol. Surv. Prof. Paper 121* (1921), p. 30.
† Includes helium and the other inert gases.

EXPLANATION

1. Fullerton field, Orange County, Cal.
2. Caddo field, Caddo and Bossier parishes, La.
3. Oil City, Clarion County, Pa.
4. Titusville, Crawford County, Pa.
5. McKittrick field, Kings County, Cal.
6. Glasgow, Barren County, Ky.
7. Petrolia field, Clay County, Tex.

1–4. Gases containing 95 per cent or more of paraffin hydrocarbons, characteristic of most of the gas used in the United States. Analyses 3 and 4, which show the high percentage of ethane, probably represent casing-head gas, that is, gas occurring in the same sand with the oil.

5. Gas high in carbon dioxide. This type is confined almost entirely to California.

6. Gas high in hydrogen sulphide. This type occurs at a number of places, but hydrogen sulphide is not present in most natural gases.

7. Gas high in nitrogen. The type region for this variety of gas is in Oklahoma, Kansas, and Texas.

Most of the natural gases used for fuel contain over 90 per cent of hydrocarbons. Table III, after Rogers,[1] shows analyses of several types of natural gas. Some of the nitrogen in the gases from the wells along the Yellowstone River might have been derived from

[1] G. S. Rogers, "Helium-bearing Natural Gas," *U.S. Geol. Surv. Prof. Paper 121* (1921), p. 36.

air incorporated in the sediments when they were originally deposited and from air carried down by ground water in its descent. Nitrogen, which constitutes about four-fifths, by volume, of the air, is very inert, a property that precludes the possibility of its chemical reaction with minerals underground; but oxygen, which constitutes almost one-fifth of the air, reacts readily with underground materials. Air dissolved in water, however, consists of about 65 per cent nitrogen, and 35 per cent oxygen.[1]

Furthermore, it has been shown that oxygen is rapidly absorbed by fresh coal without the formation of carbon dioxide for long periods of time,[2] and it is possible that considerable oxygen might be consumed in this manner by the coals and carbonaceous materials of the Lance beds, which are the source of the water and gas. R. T. Chamberlin[3] has shown that under ordinary conditions of temperature and pressure coal yields considerable quantities of methane and nitrogen, with minor amounts of carbon dioxide and oxygen (Table IV). Most of the nitrogen in the gases from the artesian wells of this area (Table II) was doubtless contributed in this manner, and it is believed that methane originated from the coal and disseminated carbonaceous material of the lance formation.[4]

Burgess and Wheeler[5] show that before the temperature of 100° C. is reached all the nitrogen has been expelled from coal and that at that temperature and up to 400° C. the gases given off are C_nH_{2n+2}, carbon dioxide, carbon monoxide, hydrogen, and hydrogen sulphide. Tests on coals from different localities and of different

[1] H. E. Roscoe and C. Schorlemmer, "A Treatise on Chemistry," 5th ed., 1920. London: Macmillan Co.

[2] H. C. Porter and F. K. Ovitz, "The Escape of Gas from Coal," *U.S. Bur. Mines Tech. Paper 2* (1911), p. 6.

[3] "Explosive Mine Gases and Dusts," *U.S. Bur. Mines Bull. 26* (1911), pp. 18–19.

[4] Dr. C. E. Van Orstrand, in a personal interview, stated that he has attempted elsewhere to determine if there is any rise in temperature at the horizons of coal beds and that he has observed no departure from the normal temperature gradient at such horizons. In this general region the normal gradient—the increase of temperature with increasing depth—is about 1° in 50 feet. The temperature conditions are therefore comparable to the conditions in Chamberlin's experiments, which are recorded at 0° C. and 760 millimeters pressure.

[5] N. J. Burgess and R. V. Wheeler, "Distillation of Coal in a Vacuum," *Chem. Soc. Jour. Trans.*, Vol. CV, Part I, pp. 131–40. London, 1914.

ages might, however, show that the gases can be given off in a somewhat different order.

In view of the foregoing statements, it is evident that the high nitrogen content of the gases from the artesian waters of this area can be accounted for by the decomposition of coal, although some of it may be of atmospheric origin.

It is an interesting fact that at a number of places nitrogenous gases contain helium. Cady and McFarland,[1] after examining over forty samples of gas from Kansas and adjacent states, show that "in general the helium content increases with nitrogen, although a direct proportionality does not appear to exist."

TABLE IV*

ANALYSES OF GASES LIBERATED FROM CRUSHED COAL

	1	2
Carbon dioxide	2.90	1.56
Methane	39.65	40.99
Oxygen	10.07	9.86
Nitrogen	38.11	37.62
Nitrogen (excess)	9.27	10.27
Total	100.00	100.00

* Percentages by volume at 0° C. and 760-mm. pressure. After R. T. Chamberlin, "Explosive Mine Gases and Dusts," *U.S. Bur. Mines Bull. 26* (1911), pp. 18–19.

Moureu,[2] after examining the gases from a number of thermal springs in Europe, showed that the high nitrogen gases contain helium, though there is no constant relation between the percentages of nitrogen and helium.

Helium-bearing gas of commercial grade is confined almost entirely to sedimentary rocks, though it is reported that the boric acid fumaroles of Italy would yield small commercial supplies.[3] To be of commercial importance a gas must contain 0.5 per cent or more

[1] H. P. Cady and D. F. McFarland, "Helium in Natural Gas," *Amer. Chem. Soc. Jour.*, Vol. XXIX (1907), pp. 1523–35.

[2] Charles Moureu, "Recherches sur les gaz rares des sources thermales," *Soc. chim. France Bull. 9* (4th ser.), Vol. XXV (1911), pp. i–xxv.

[3] R. B. Moore, "Helium, a Natural Asset," *Amer. Inst. Min. and Met. Eng. Trans.*, Vol. LXIX (1923), p. 116

of helium. E. T. Allen's tables of volcanic gases from many parts of the world[1] show a maximum of 0.01+ per cent of helium, though many of these gases contain as much as 90 per cent of nitrogen.[2] It is true that many of the volcanic gases represented in Allen's tables were analyzed before helium was discovered, but the fact that none of the samples tested for helium show appreciable quantities suggests that it is of relatively slight importance in volcanic gases in general.

Rogers[3] has pointed out that the Cretaceous and Tertiary strata are characteristically poor in helium and that rocks of these systems are also poor in nitrogen. The region along Yellowstone River is rather exceptional, therefore, as the nitrogenous gas of this region is derived from rocks of the Tertiary (?) Lance formation. Rogers has also pointed out that in the mid-continental area the best grade of helium-bearing gas comes from relatively shallow depths—that is, of the magnitude of a few hundred feet rather than a thousand or several thousand feet. The maximum depth of the wells in the area here considered, as shown in Table I, is 580 feet.

A considerable amount of gas is required for a helium determination, and when samples of the gases shown in Table II were collected, only small samples were taken, as the high nitrogen content was unexpected. For this reason these samples have not been analyzed for helium.

Although the high nitrogen content of these gases suggests that they may contain helium also, the facts that natural gas in commercial amounts has never been discovered in the Lance formation in this region and that Tertiary rocks in general are very unfavorable as sources of helium lead to the belief that the discovery of commercial quantities of helium in gases from the Lance formation in this region is at the present time extremely unlikely. The discovery of even small quantities of helium in gases from these beds would, however, be of scientific interest.

[1] E. T. Allen, "Chemical Aspects of Volcanism, with a Collection of the Analyses of Volcanic Gases," *Franklin Inst. Jour.*, Vol. CXCIII (1922), pp. 70–80.

[2] For additional analyses of high nitrogen gases see F. W. Clarke, "The Data of Geochemistry," *U.S. Geol. Surv. Bull. 695* (4th ed., 1920), pp. 256–64.

[3] G. S. Rogers, "Helium-bearing Natural Gas," *U.S. Geol. Surv. Prof. Paper 121* (1921), p. 92.

INTERPRETATION OF WATER AND GAS ANALYSES

The high concentration of the sulphate radicle in water analyses 1 and 2 (Table I and Fig. 3) and the deficiency of this radicle in water analyses 3–10, together with the absence of methane in gas analyses 1 and 2 (Table II) and the presence of methane in considerable quantity in gas analyses 3–10, demand an explanation.

Rogers[1] pointed out that Eichler[2] as early as 1874 showed that the ground waters associated with the oil in the Caucasian fields contain no sulphate, and in 1909 Engler and Höfer[3] showed that the same condition exists in several oil fields in Europe, Asia, and North America. The absence of sulphate was considered to be due to the reducing action of hydrocarbon, with the resulting formation of hydrogen sulphide. Höfer's hypothetical reactions are essentially as follows:

$$CaSO_4+CH_4=CaCO_3+H_2S+H_2O \qquad (1)$$

or

$$CaSO_4+CH_4=CaS+CO_2+2H_2O=CaCO_3+H_2S+H_2O. \qquad (2)$$

Later work by Starke[4] and Rogers[5] tends to confirm these reactions.

If somewhat similar reactions are assumed to have occurred in Rosebud County, the differences in composition between water and gas analyses 1 and 2 and water and gas analyses 3–10 (Tables I, II, and Fig. 3) are readily explained; the only difference being that in this area coal, carbonaceous seams, and disseminated carbonaceous material in the sandstone and shale, instead of oil, constitute the source of the methane, and the following reactions seem applicable:

$$NaHSO_4+CH_4=NaHCO_3+H_2S+H_2O \qquad (3)$$

$$Na_2SO_4+CH_4=Na_2CO_3+H_2S+H_2O. \qquad (4)$$

[1] G. S. Rogers, "The Sunset-Midway Oil Field, California: Part II, Geochemical Relations of the Oil, Gas, and Water," *U.S. Geol. Surv. Prof. Paper 117* (1919), pp. 26–28.

[2] W. Eichler, "Einige vorläufige Mittheilungen über das Erdöl von Baku," *Soc. imp. nat. Moscou Bull.*, Vol. XLVIII (1874), No. 4.

[3] C. Engler and H. Höfer, *Das Erdöl*, Vol. II (1909), p. 28.

[4] E. A. Starke, cited by G. S. Rogers, "Chemical Relations of the Oil-Field Waters in San Joaquin Valley, California," *U.S. Geol. Surv. Bull. 653* (1907), p. 7.

[5] G. S. Rogers, "The Sunset-Midway Oil Field, California: Part II, Geochemical Relations of the Oil, Gas, and Water," *U.S. Geol. Surv. Prof. Paper 117* (1919), pp. 26–28.

The hydrogen sulphide thus liberated would combine with oxides of iron or other metallic elements, especially in the absence of oxygen, to form pyrite or other metallic sulphides. The reaction of methane with calcium and magnesium sulphates in these waters, according to equations 1 or 2, has very probably caused some deposition of calcium and magnesium carbonates.

Additional data which tend to confirm the belief that coal, carbonaceous seams, and disseminated carbonaceous material are the source of the methane in this area are obtained by a study of the waters from the underlying marine Upper Cretaceous (and therefore non-coal-bearing) strata, all of which are high in sulphate. The lack of reduction of the sulphate in these waters is presumably due to the small amount of methane generated in these marine Cretaceous beds, most of which are dark-colored shales which undoubtedly contain considerable organic matter and which surprisingly do not seem to yield any considerable amount of methane.

The inference that this reaction takes place seems to be confirmed by a study of the water and gas analyses in Tables I and II. With the field relations in mind, a consideration of these tables leads one to conclude that in well 1 all the methane that is being evolved from carbonaceous material in the Lance formation is being consumed by reduction of the sulphate in the water to form hydrogen sulphide and that in wells 3–10 essentially all the sulphate has been reduced, with the formation of carbonates and bicarbonates (Fig. 3). In the water from these eight wells (3–10), essentially all of whose sulphate has been reduced, methane is plentiful (Table II). The conditions are somethat different in well 2; the water from this well contains considerable sulphate, and the gas in the water contains no methane and no noticeable amount of hydrogen sulphide. The explanation of these chemical relations probably lies in the fact that this well does not encounter any appreciable amount of carbonaceous material, either bedded or disseminated, from which methane might be contributed to the water, and as there is no methane present, there can be no reduction of the sulphate, and hence no hydrogen sulphide is being liberated.

The chemical interpretations set forth above seem to warrant the conclusion that in well 1 the sulphate is being reduced by

methane; in well 2 there is no methane, and therefore no reduction of sulphate; and in wells 3–10, whose waters yield abundant methane, essentially all the sulphate has been reduced. Carbon from the coal and carbonaceous shale is also probably an agent tending to reduce the sulphate in these waters.

No explanation is offered to account for the higher concentration of dissolved salts in water samples 1 and 2 (Table I), although it may be explained by local differences in the geology. Might the conditions be such that the reduction of sulphate would tend to decrease concentration?

Gas-bearing ground water occurs, not only in the known oil and gas fields, but in a variety of geologic environments, including metal mines, coal-bearing strata, and artesian basins, notably the artesian basin of the Dakotas, but systematic geologic studies of the ground water and associated gas in these types of environment are almost wanting so far as the author is aware. Doubtless, studies of gases contained in ground water together with a consideration of the geology involved will aid in interpreting certain of the chemical changes which take place underground.

SUMMARY

1. There are a number of artesian wells along Yellowstone River in central Montana which yield gas-bearing water derived from the Lance formation. Ten typical samples were collected, and the results of water and gas analyses are shown in Tables I and II and Figure 3.

2. The waters from these wells are all high in sodium and very low in calcium and magnesium. The sulphate radicle is high in wells 1 and 2 and negligible in wells 3–10. The bicarbonate radicle is high in all ten samples, but especially in wells 3–10, which are low in sulphate.

3. The gases from all ten of these artesian waters contain over 30 per cent of nitrogen. Samples 1 and 2 (Table II), the waters of which are high in sulphate, contain 95 per cent or more of nitrogen and no methane. The methane in the others is derived from the Lance coals, and disseminated carbonaceous material in the sand-

stones, and shales. Sample 1 contains noticeable amounts of hydrogen sulphide. Oxygen is unimportant in all samples.

4. These nitrogenous gases may contain some helium, but there is little likelihood that helium is present in important amount.

5. An inspection of the chemical analyses of the waters and gases shows that the methane reduces the sulphate to hydrogen sulphide forming carbonate and bicarbonate. Similar reactions have been reported by Rogers and Starke as occurring in the waters in oil fields.

SOME INCLUSIONS IN BASALTS

STEPHEN RICHARZ
Techny, Illinois

ABSTRACT

Inclusions of granite, sandstone, and shale in the basalts of northern Bavaria are described. The feldspars, in most instances, are partially changed to sanidine, and the quartz is partially fused to glass. By-products of the alteration are diopside, aegirite, and kataphorite, derived from the basalt, and spinel and sillimanite derived from the mica. In other places fusion into glass predominates, with accompanying cordierite, spinel, and sillimanite.

The study of inclusions of foreign material in igneous rocks has always been considered as of great importance for the correct understanding of the reactions exerted by intruded magma or by outflowing lava. Not only the petrologist but also the geophysicist and the chemist are interested in the questions arising from these researches. However, the petrologist, by a thorough microscopic examination of the facts, has to furnish a solid base for all other work.

The writer examined, some years ago, inclusions in basalts of northern Bavaria. Although the results of these researches have been published,[1] it may not be out of place to summarize here the facts concerning the inclusions and their metamorphism, because these facts are of more than local interest, and they tend to enrich our knowledge of the subterranean forces.

A *nephelite basalt* which is extraordinarily rich in inclusions is exposed in a quarry near Groschlattengrün to a height of about 40 meters, and of considerable horizontal extension. The basalt is a porphyritic rock with phenocrysts of olivine, while titaniferous augite, rare among the phenocrysts, is the chief mineral of the groundmass where it is accompanied by magnetite and nephelite, the latter in clusters without crystal form. Biotite is also found, mostly in these nephelite clusters. The rock is a very basic one

[1] Steph. Richarz, "Die Basalte der Oberpfalz," *Zeitschrift der Deutschen Geologischen Gesellschaft*, Vol. LXXII (Berlin, 1920), pp. 1–100.

(38 per cent silica), belonging to the alkalic group with soda prevailing—4 per cent against 2 per cent potash.

The inclusions were mostly derived from the large granitic massif through which the lava was extruded. They are, as a rule, very small and altered to a high degree. One would hardly identify them as granite, without microscopic examination. Obviously the quartz was cracked by the heat, the cracks being filled with glass, which later, in many cases, was changed to chalcedony. The potash feldspar is the same as in the surrounding granite, the perthite lamellae still preserved, but the axial angle has been diminished to about 0°. The plagioclase, an andesine approaching labradorite, retained its lamellar twinning and its freshness; usually, however, it has a rim of a feldspar without lamellae, whose refraction is the same as that of the adjoining orthoclase, and whose negative axial angle approaches zero. The same feldspar, apparently *sanidine*, is found in cracks in the andesine; in some instances only a few fragments of this plagioclase are preserved, rounded, and imbedded in sanidine. Orthoclase, also, occasionally appears in rounded grains and rimmed with sanidine.

Mica is no longer present. Spinel and fibers of sillimanite occupy its place. Rutil and anatase seem to point to an original biotite. Cordierite, usually found in such inclusions in other places, was never observed. There are two more minerals always present in these granitic fragments: the zeolite natrolite, and a colloidal silicate which is very similar, in its physical characteristics, to cerolite, differing chemically, however, since it contains 24 per cent Al_2O_3 and 40 per cent MgO (molecular percentage), besides a great amount of water. On account of these compounds the new name *magnalite* seemed to be appropriate.

Even of greater interest than the inclusions themselves is the immediate contact with the including basalt. The inclusions are surrounded by a black rim, 1 to 2 millimeters wide, in which magnetite and biotite are more abundant than in the normal basalt, and the phenocrysts of olivine are more altered (into an iddingsite-like substance). Close to the inclusion the olivine disappears altogether, as also does the nephelite, and this zone, of the same width as above, contains only magnetite and biotite and the titanium augite of the

basaltic groundmass. The latter, in approaching the inclusion, loses its brownish color and grows into long, well-bounded dark-green crystals which, even with the unaided eye, may easily be identified as *diopside*.

This diopside stretches its pyramids into a feldspar with all the optical characteristics of sanidine. There are also well-formed crystals of diopside swimming, as it were, in this sanidine. Glass, as a concomitant of sanidine, is very rare in this part of the inclusion, but there seems to be sanidine in an amorphous state accompanying the crystallized form.

Two other minerals, rich in soda, require special attention: the pyroxene *aegirite* and the amphibole *kataphorite*, both found, either as independent crystals, or intergrown zonally and also with diopside. These minerals, although nowhere of any amount, are never missing in the contact zone of the granitic inclusions. The original granite being a normal calc-alkali rock, these soda minerals, and very likely also the sanidine, are only to be accounted for by a diffusion of the alkalic substances of the sodic basalt into the inclusions. And therefore, in the contact zone of the basalt, no more nephelite is to be found and the soda-bearing titaniferous augite is partially replaced by diopside.

There are in the same locality also inclusions of sandstone. These, too, are surrounded by the same contact zone, containing sanidine, diopside, aegirite, and kataphorite. The margin of the quartz grains was fused into colorless glass; the clayey cement has been changed to a brownish amorphous substance. If the clayey matter was prevailing in the original rock, the inclusion became hard, porcelain-like basalt jasper.

The other basalts of the numerous volcanic vents in the area studied are somewhat different. In most of them we find phenocrysts of olivine and of titanium augite in equal amount. In many cases a basic plagioclase accompanies the nephelite of the groundmass; in other localities nephelite is absent and small lamellae of basic plagioclase and some glass are the only light constituents. Yet, nearly everywhere, the metamorphism of the granitic inclusions is about the same as just described. Orthoclase and plagioclase have always a rim of sanidine, which also surrounds the inclusions,

and is accompanied by diopside, aegirite, and kataphorite, whereas quartz is encompassed by glass or has been wholly changed into glass.

Quite another form of alteration of the granitic fragments took place in a feldspar basalt near Triebendorf which shows up as an enormous dike, 500 meters in length and 200 in width. Here the inclusions are larger; even a bowlder of 75 to 40 centimeters was seen. To the unaided eye the minerals and the structure of the granite are readily recognizable. But the alteration is visible even to the center of the large bowlders, namely, as green glass extending through all the minerals, and a dense pitchy slag, formerly biotite.

Under the microscope the basalt, close to the inclusion, shows no alteration except an enrichment in glass. The brown glass of the basalt penetrates the inclusions, assuming violet or yellowish colors, and contains crystals of diopside. Farther from the basalt the glass is colorless and flows, as it were, through all the other minerals, even to a great distance from the host. Thus the orthoclase, again with a small axial angle, is veined by glass, the andesine is broken into fragments cemented by glass, and the quartz contains numerous glassy inclusions of various shapes. The biotite is altered to a brownish glass containing numberless crystals of spinel and fibers of sillimanite. Also *cordierite* is a common by-product of the fusion process. Sanidine was, once in a while, observed near the basalt; but aegirite and kataphorite are lacking.

How may this difference in the metamorphism of the granite be accounted for? It cannot well be explained by the difference in the basaltic host, because there are basalts in the neighborhood of quite the same composition; but nevertheless the inclusions have been changed in the same way as in the nephelite basalts. Possibly the field observation gives a clue. As mentioned before, these basalts occur in the form of a wide dike which is intruded in basaltic tuffs. Moreover, near the western end of the outcropping of this dike, a tuff protrudes through the solid rock, on all sides surrounded by basalt. And it was just close to this tuff that all the large granitic fragments were found. So it is very likely that here the greater heat caused a more thorough fusion of the granitic minerals

than in other places.[1] This hypothesis is confirmed by the fact that smaller fragments, taken from other parts of the dike, show less fusion and more the described conversion into sanidine.

In the southern part of the basaltic area the lava was extruded through sandstones and shales of Upper Triassic age (Keuper), and numerous fragments of these are found in the basalts and their tuffs. The sandstone has been fritted, and the shales have been altered to basalt jasper. There are bowlders of 1 cubic meter wholly changed to this hard rock, whereas, in one instance, the crater walls, though in contact with a solid lava cone of 60 meters in diameter, are only metamorphosed to a distance of less than 1 meter.

In these sandstone and shale inclusions the quartz is partially fused to a colorless glass, the clayey cement and the shale to a brown glass. In some cases here also sanidine was observed, accompanying the glass. By-products of the metamorphism are: spinel, cordierite, and sillimanite. Scattered through the basalt there are many quartz grains, which doubtless have been taken from the sandstones. They are surrounded by diopside, grading occasionally in aegirite and kataphorite. These minerals are swimming either in sanidine or in glass. Small quartz grains may have been totally resorbed, and only the pyroxene in sanidine or glass remained. There were also found single grains of potash feldspar encompassed by a rim of sanidine.

[1] N. L. Bowen, "The Behavior of Inclusions in Igneous Magmas," *Journal of Geology*, Vol. XXX, p. 522.

EDITORIAL

PROPOSED OCEANOGRAPHIC RESEARCH BY THE NAVY

To the geologist oceanographic research is growing both in importance and in comprehensiveness. Interest in the study of sediments and sedimentation increases. The evidence of past climatic changes excites more active thought on the causes of present regional climate and its changes. Paleontology, biogeography, and paleogeography point with greater definiteness and refinement toward constant shifting of coasts and continental connections. Finally, rapid sonic sounding promises more clearly to show the physiography of the continental shelf with its submerged relief and to reveal in unprecedented detail the topographic and structural features of the ocean bottom, including, of course, regions of submarine faulting and vulcanism. The navy project for systematic and comprehensive oceanographic exploration is therefore of unusual interest.

The plan proposed is broader in scope than that of any preceding exploration. It responds to the need for more diversified as well as more detailed knowledge of air, water, sea life, and ocean bottom to accord with the progress of science and the development of invention in aeronautics, radio, submarine transmission of sound, etc. It naturally embraces the study of the temperatures, densities, and salinities, with measurement and mapping of the ocean currents at different depths, and the collection of data as to their periodic changes. This is most important to the interpretation of climates both on land and sea, and through consequently more accurate weather prediction, it should be of very great benefit to agriculture as well as shipping. Visibility, static disturbances, and investigations of other phases of electricity in the atmosphere will be added to ordinary meteorological objectives, and studies will be made of the penetration and diffusion of light in sea water under varying conditions. Gravity at sea will be observed provided equipment practicably adapted for such use is at hand, which, in view of the

fact that A. A. Michelson, F. E. Wright, and L. J. Briggs are engaged in designing new apparatus for gravity measurement, is rather confidently expected. The height, length, velocity, and other features of ocean waves will be made the objects of special study needed for better nautical designs and other purposes. Attention is to be given to the chemistry of sea water, its hydrogen-ion concentration, nitrogen, etc., as well as its movement and temperature as related to the life and to the bottom.

The study of the plant and animal life of the sea, its distribution, relative abundance, and interrelations, is accorded importance not inferior to the physical investigations, for a systematic, well-ordered, and thorough knowledge of sea life and of the mutual relations of the plants and animals to one another and to the water may not be less valuable in the day, perhaps less than a half-century distant, when the farming of the sea will of necessity be methodically pursued for food for the world's increasing population. The biology of the expeditions is to be worthy of the name rather than the mere biology of the less minute kinds of animal life, as has generally been the case with later American oceanographic explorations, in which diatoms and other organisms small enough to drain off with water through the sieve or slits in the barrel staves appear generally to have been immediately thrown away. I may add that the neglect of the study of the complete plant life, the foundation of animal life, and even of a large part of the microzoan material in our American oceanographic enterprises, is notorious. This is one reason why specialists qualified to undertake the study of some of the groups of organisms have not been developed in this country, and it explains why we are so much at loss for data as to some of the primary and fundamentally important food supplies of the sea life that interests us commercially. The present annual value of our fisheries products is about eighty-seven millions of dollars. It is not unlikely that new fishing banks will be discovered besides determining the off-season residences of various kinds of fish which occupy the known fishing grounds during only portions of the year. Most geologists may not know that British fishermen go as far as the Falkland Islands, and that trawl fishing already reaches to a depth of 200 fathoms, and is proved to be possible down to a depth

of 300 fathoms. The progress of industry drives forward scientific research.

The principal sources of interest to the geologist lie in the wealth of information on submarine topography and structure to be obtained by means of Hayes's "Sonic Depth Finder," and in the sampling and study of the bottom sediments. With soundings at a rate of several per minute, i.e., a new detonation immediately following the receipt of an echo of the last—and with an error of but about 1 per cent at moderate depths, profiles of the bottom will actually accompany the ship. Crests, horsts, grabens, submarine volcanoes, terraces, declivities, and fault scarps can be located and mapped through considerable areas with relative accuracy and at amazing speed. Detailed work in any extensive area will go far toward unraveling its physiographic history. There will be times when the geologist will wish to stay on deck twenty-four hours a day.

Bottom sampling will be governed both by the topography, as it is disclosed, and by the life on and above the sea floor. In fact, the mutual relations of water composition, movement, and temperature, and of the associated life to the underlying bottom, on the one hand, and, on the other, of the physical and chemical composition of the sediment to the overlying water and its included life should be given special consideration. So far as practicable, examinations, both microscopical and biochemical, of certain types of sediments of organically chemical composition that cannot very satisfactorily be investigated in some laboratory after pickling, canning, or drying, will be carried on in a laboratory on the ship, in which the sedimentarian will have the co-operation of a biochemist or a soil chemist, or both.

By means of apparatus already in use it should be possible under favorable conditions to take core samples of the bottom to depths of 3 or even 6 feet, according to conditions. If this is successfully done, the cores may be examined with great profit by the trained sedimentary petrologist. Some of them should show the dust layers caused by the Katmai, the St. Vincent, the Krakatoa, and earlier volcanic explosions. In some cases these dust films or layers may be close to one another; in other areas they will be more distant. The observations may, accordingly, lead not only

to accurate determinations of the rate of sedimentation in different areas and under different conditions, but, through the determination of the thicknesses laid down during known periods, it may be possible to calculate the time intervals between other, earlier, explosions recorded in the cuttings, but not in written history. Invaluable information should come from the investigation, on the spot, of the mode of deposition of many types of sediments, such as not only the carbonates but the bogheads, black shales, calcareous bituminous shales, or carbonaceous limestones, in which débris of organic composition is preserved in the deposits, and in which biochemical decomposition may be seen in progress. The study of these samples should throw light on the question of the preservation of soft parts of animals, particularly animal fats, in the sediments, to accord with a prevalent theory of the organic origin of petroleum.

The physical and meteorological observations are to be cared for by navy officers detailed for the purpose. For the conduct of other scientific work there will be an oceanographer in charge, a biologist, and a geologist, all of whom should be men of broad training, experience, and scientific standing. Six scientific assistants, chosen largely for qualifications as specialists in fields in which the chiefs have not specialized, will aid and supplement their work. The oceanographer will presumably be a zoölogist, and the biologist should be generally familiar with the plant life of the sea. One assistant may be a chemist and another a biochemist or a soil chemist. One or both will co-operate with the geologist in the study of sediments on shipboard.

The plans call for a twin-screw ship of moderate size which, besides having ample accommodations for officers, scientific staff, storage, and equipment, will have laboratory space for the photographer, who will be a navy officer, for the oceanographer and the biologist, for the chemical and sedimentary work, and for drafting and map study. The soundings should be platted as fast as taken in order that the geologist or other members of the staff may be aware of and profit by unforeseen opportunities for special local studies or sampling as they are presented on the spot. The tremendous advantages over all previous expeditions, and the efficiency and economy to be gained by having ready at hand competent

specialists in geology or biology are obvious. The geologist who finds the ship crossing a previously unknown rift, scarp, or ridge can immediately advise the commanding officer as to the directions, the distances, and the amount of maneuvering necessary to ascertain adequately the trend, character, maximum and general relations of the features. Thus the greatest amount of unnecessary cruising and time may be saved. The biologist instantly recognizing a very remarkable or unique life-occurrence or relation should be able thereupon adequately to confirm and complete a discovery which, as with the geological discovery, might otherwise rest in incompleteness and uncertainty for many years.

It is expected that the civilian scientific staff will be contributed by the scientific bureaus of the government or by other scientific and educational institutions. Voluntary services of research students and of professors enjoying sabbatical years are anticipated, and it is accordingly planned that the ship shall have accommodation for volunteer research assistants and specialists not included in the regular scientific staff, for there will be many problems of scientific or economic importance thus to be taken care of on the ground. When near a relatively little-known coast, an additional geologist may be needed to study the physiographic features of the land, to collect fossils, secure structural data, etc.

Evidently the geologist must be a man of broad training and interest. He must be both a sedimentarian and a physiographer, with knowledge and experience in tectonics; otherwise, one of the assistants must supply special training and experience. He also will advise regarding gravity stations, presumably with good judgment as to where gravity measurements will be most useful and most interesting, this question being ruled largely by the topography and evidences of submarine structure. He should also be competent to contour the sonic-depth data intelligently, with reference to structure and drainage pattern.

The committee proposes that detailed exploration be pursued in a given region, instead of extended reconnaisance cruises in different parts of the world, and the conference recommends that attention first be given to the Caribbean and Gulf regions, with exploration of a tract reaching to the Azores, and with the extension

of studies from the Panama Canal to the Galapagos Islands, which in geologic interest are comparable to the Hawaiian group. Finally, the plans are formulated on the assumption that the oceanographic explorations will be continued indefinitely by the Navy Department and, according to the expressed wishes of the Department, that the scientific investigations will be conducted co-operatively with other departments and scientific bureaus, as is foreshadowed in the make-up of the scientific personnel and advisory committee.

The natural-history collections will eventually, according to law, be transferred to the United States National Museum, which will make record of their sources, general nature, and movements from the time that they are landed. It is proposed, however, that the disposition of the material, including bottom samples of course, for study, will be in accordance with mutual agreement between the Navy Department and the Museum. This rule, if adopted, predicates a continuing scientific steering committee on the part of the Navy Department. Publication of results will be by the Navy Department or under such regulations as the Secretary of the Navy may prescribe.

DAVID WHITE

DIVISION OF GEOLOGY AND GEOGRAPHY
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C.
November 3, 1924

REVIEWS

The Earth, Its Origin, History and Physical Constitution. By HAROLD JEFFRIES. Cambridge: University Press, 1924. Pp. 278.

The following chapter heads indicate the range of subjects treated: "The Nebular Hypothesis of Laplace"; "The Tidal Theory of the Origin of the Solar System"; "The Origin of the Moon"; "The Resisting Medium"; "The Age of the Earth"; "The Thermal History of the Earth"; "The Equations of Motion of an Elastic Solid with Initial Stress"; "The Bending of the Earth's Crust by the Weight of Mountains"; "The Theory of Isostasy"; "The Thermal Contraction Theory of Mountain Formation"; "Theories of Other Surface Features"; "Seismology"; "The Figures of the Earth and Moon"; "Tidal Friction"; "The Variation of Latitude." Appendixes: "The Planetesimal Hypothesis"; "Jeans' Theory"; "The Hypothesis of the Indefinite Deformability of the Sun by Small Stresses"; "Theories of Climatic Variation"; "Empirical Periodicities."

This is a wide range of themes to be treated in a small book, while the subjects themselves seem somewhat disconnected, but a common strand of thought runs through them and gives the treatment a unity not apparent on the surface. This unity springs from the advocacy of a theory of earth-genesis, and this is projected into its bearings on leading earth-problems. A consistent review should therefore give primary attention to the genesis offered and secondary attention to the applications.

The Laplacian hypothesis.—After an introduction of the usual type, the discussion opens with a sharp criticism of "Laplace's account of the Nebular Hypothesis." This is characterized as "exceedingly vague, no quantitative discussion whatever being included." This gives us at the outset a key to the author's point of view. The author, however, at once makes amends for his severity by giving a translation of Laplace's account from which the reader may form his own impressions. It is true that the account of Laplace is entirely devoid of mathematical formulation, though Laplace was one of the world's greatest mathematicians. As a mathematician of deep penetration, Laplace probably realized that some of the factors of earth-genesis could not be given exact quantitative expression, and that he faced the alternative of either using uncertain

estimates as premises to be treated by *exact processes* (giving a semblance of precision but retaining the errors as faithfully as the truths) or else of dealing with uncertainties frankly as they necessarily are. It does little good to make a show of formulistic treatment of some of the factors, if the rest cannot be formulated and are ignored on that account. Laplace's statement has usually been admired for its candor, simplicity, and fidelity to the state of knowledge of his day. We are among those who think his theory was very faulty, but that it was still a great contribution for its day.

Though a well-worn subject, Jeffries gives the shortcomings of the Laplacian theory a fresh treatment. He introduces some new arguments, and gives some old arguments new dress. He concludes that the theory is untenable, a view now quite commonly held by those who have carefully studied the dynamical peculiarities of our planetary system.

The discussion of other theories should naturally have followed, but a break in historical continuity occurs, which is explained thus:

> Descriptions will therefore be given of the two chief theories that preceded the present one, namely, the Nebular Hypothesis of Laplace and Roche, and the Planetesimal Hypothesis of Chamberlin and Moulton. It has, however, been found more convenient to treat the latter in an Appendix than to place it in its proper historical position, which would have been immediately after the Laplacian theory [p. 3].

By reference to the Appendix, however, it will be seen that, while the author frankly recognizes that "the Planetesimal Hypothesis was historically the parent of the Tidal Theory of the Origin of the Solar System, elaborated in chapter ii" (p. 250), he does not give the specific tenets of the theory which the reader needs for comparison with the derivative theory. It therefore falls to the reviewer to supply at this point what seems necessary.

The planetesimal hypothesis is the parent of two outstanding cosmologic tenets: (1) That the planets have arisen from *dynamic* encounter: to wit, a star passing the sun *at a distance* stimulated it, by tidal stresses, to shoot forth small parts of its substance to great distances, the passing star drawing them forward into orbits; these ejections, erupted from the sun as belches or bolts, separated as they shot onward into central parts which remained under self-control and formed nuclei which became collecting centers, while the outer parts were scattered into orbits concurrent with the nuclei and formed planetesimals. (2) That the aggregation of the planets arose from a *concurrent orbital* organization by orbital dynamics, not from a gaseous or meteoritic organization by gaseous or

meteoritic dynamics. The distinctions between the orbital mode of organization, the gaseous mode of organization, and the meteoritic mode of organization, respectively, *are strictly dynamical distinctions*, and are imperative to clear thinking. In the case in hand, the orbital elements include both the nuclei and the planetesimals, and the planetesimals may have been either atoms, molecules, or aggregates. The planetesimal feature consists in *assemblage in concurrent orbits* of the planetary type. The meteoritic type of organization consists of *assemblage in discordant orbits*. Gaseous organization consists of *assemblage in collisional relationships*, or, as someone has put it, "jostling mob organizations." The distinct recognition of *concurrent orbital organization* as a leading factor in planetary evolution is a more distinct contribution to cosmology than has been appreciated, and contributes a distinctive factor to subsequent earth-history.

The recognition of the planetesimal type of organization takes something away from what had commonly been referred to the gaseous domain, on the one hand, and to the meteoritic, on the other. Very naturally there are gradations between the three forms of assemblage but these cannot be noted here. There are also other types of assemblage of atoms, molecules, and aggregates, but they do not need to be distinguished in this connection.

Out of the doctrine of dynamic encounter grew the erupto-tidal subtheory indicated above. This is embraced within the planetesimal hypothesis, as one of its working features. In this sub-theory, the star does not act alone as a tide-producer, but, of necessity, acts concurrently with the convectional and eruptive activities and potentialities of the sun in projecting a very small fraction of the sun (one-seventh of 1 per cent, plus loss) to the requisite distances. In doing this the star's attraction gives the ejected matter transverse motion which results in orbital courses, partly as nuclei and partly as planetesimals. As the convective and eruptive potentialities of the sun are now very great, and probably always have been great, the star need only approach near enough to call forth a part of those potentialities, and so stars of quite different masses and degrees of approach might be effective, all the more so because their actions were rather trigger-pulls than actual propulsions. This action at long distances left room between the star and the sun for the deployment of the planets-to-be, a most vital matter, as we shall presently see. The collection of the planetesimals into the nuclei was necessarily slow, for it was an orbital matter, not a simple condensation. This greatly affected the condition of the planetary bodies as they were growing up

from nuclei into mature planets, hence the geological importance of the theory.

It will thus be seen, even from this brief sketch, that care must be taken at all steps in the evolution to distinguish the *dynamical states* of the formative material. It is especially to be noted that the lines of these necessary distinctions do not coincide with the ordinary distinctions between gases, liquids, and solids, any more than they do in distinguishing planets from other bodies. Planets embrace all three states, as the planetesimals also may and probably do.

The tidal theories of Jeans and of Jeffries.—The term "tidal" has been used in so many previous relations that it is almost barred by preoccupation from use as the special name of a new theory. "Tidal theory," used relative to the origin of the earth, almost inevitably calls to mind the tidal separation of the earth and moon, which commanded wide attention for many years because of the able advocacy of Sir George Darwin. So, too, the erupto-tidal sub-theory of the planetesimal hypothesis anticipated the tidal theories of Jeans and Jeffries, and in a very similar sense.

The tidal theory of Jeffries, as set forth in *The Earth*, is not altogether identical with the tidal theory of Jeans, offered in *Memoirs of the Royal Astronomical Society*, Volume LXII (1917), pages 1–48, and in *Problems of Cosmogony and Stellar Dynamics*, 1919. In most essentials, however, Jeffries has accepted Jeans's views. Jeffries' departures from Jeans seem to the reviewer to be distinct improvements. In the first place, Jeffries puts his views explicitly into their due relation to the earlier views from which the tidal theory sprang; he frankly acknowledges the parental relations of the planetesimal hypothesis to the tidal theory (p. 250). This gives his views good ethical standing, and with that goes unquestionable liberty to try to splice a new top on an older stump. It is entirely legitimate to graft a preferred limb on any living stock that will support it—a pear on a quince, if you please—provided proper care is taken of the supporting stock. But of course stumps will not give life to all kinds of limbs that may be spliced on to them.

In the second place, Jeffries recognizes more fully the actualities of the case, though not with adequate fulness. He is clearer and more explicit in his expositions. There is much less shrouding of the vulgar facts of nature in the celestial atmosphere of the mathematical Parnassus, but still there is quite too much of it.

Of the concrete divergencies, the most important is Jeffries' limitation of the ancestral sun to a radius of 21,000,000 kilometers, thus leaving the planetary field outside and unoccupied by the sun during the formation

of the planetary system, whereas Jeans filled the whole present planetary field with his theoretical sun. To this occupancy Jeffries raises three objections—one based on temperature, one on density, and one on the absence of a competent agency to bring the planets into their present positions. In addition to these, others will appear as we go on.

Jeffries' statement of his theory follows:

> The fundamental feature of the hypothesis is the approach to the sun of a star considerably more massive than itself. This raised two large tides on the sun, the greatest protuberance being at the points of the sun nearest to and farthest from the star. When the distance between the two bodies became sufficiently small, the tendency to disruption due to the difference between the attraction of the star on the two opposite sides of the sun became greater than the sun's gravitation could counteract, and a portion of the sun was torn away. This afterwards condensed to form the planets and satellites [p. 17].

The approach of a star to the sun (and consequent tidal action) is taken over from the planetesimal hypothesis, but two modifications are introduced, both of which limit the scope of tidal action: (1) as specified, the star must be more massive than the sun; (2) the convective turbulence and the eruptive potentialities of the sun are not taken into account. This is not merely implied by the omission of any mention of these factors in the quotation, but by the specification that the star must be more massive than the sun. This limitation would not be necessary if the chief ejective agency were referred to the eruptivity of the sun, for in that case little more than trigger-action and directive action would be required of the star. This neglect of a very potential agency, and what it leads to, constitute the chief basal difference between the tidal theory and the planetesimal hypothesis. The divergence was of course widened step by step as other issues came under consideration.

The working aspects of the tidal theory.—Bearing these divergencies and limitations in mind, let us turn to the working aspects of the theory. We catch these best by means of Figure 1 (p. 18 of the book under review), which is here reproduced for the purpose. This is a triply authenticated figure. It appeared in Jeans's first paper on "The Tidal Theory" (*op. cit.*, p. 31), in his *Problems of Cosmogony*, and has Jeffries' implied indorsement by its use in the text under review. It fairly represents the basal tenets of the theory. The lines of the figure represent instantaneous equipotential surfaces due to the sun (M) and the star (M') at the critical instant of action, in a case in which the star has twice the mass of the sun, and the distance of their centers apart is 2.87 times the undistorted radius of the sun. The critical instant is that at which solar matter completely

fills the space within the heavy line and is just about to pour out a jet or filament at the point on the right, this outpour being the source of the planets. In addition to these particulars, the case is made a quite special one by its basal assumptions. These are best stated by Jeans in connection with the original figure in his first paper, as follows:

> Suppose that the primary [the sun] is made up of some matter of infinite density and some of zero density; the former will be approximately a mass of infinitesimal size and mass M_0, the latter will form an atmosphere of negligible mass surrounding the core [*op. cit.*, p. 30].

This supposititious distribution of density simplifies the mathematical treatment, but we must consider whether it represents the essential

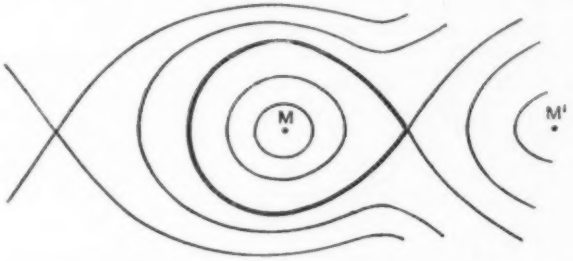


FIG. 1.—(From Jeans's *Problems of Cosmogony*.) Reproduced from Jeffries' *The Earth, Its Origin, History and Physical Constitution*, p. 18. M = sun; M' = star; lines = equipotentials; heavy line represents critical state.

realities of the case in a working sense. By reference to the figure reproduced, it will be seen that the sun and the star are consistently represented by very small dots, and that there is no representation at all of the outer substance of the sun or of the star. In keeping with this, further, the author habitually speaks of "the envelope" and not of the outer part of the sun. It will be seen, in further consistency, that no matter is represented as filling the pointed cone at the critical moment when it is about to pour out matter to form the jet or filament which, in turn, is to form the planets. All this supports the explicit statement that the atmosphere is "negligible" in mass. The first point to be noted is that this distribution of mass is the basis on which the equipotential lines of the figure were computed, and that if there is any serious working defect in this distribution, it affects correspondingly the whole structure built upon it. Leaving this point for the moment, let us consider the working aspects.

It is obvious that adequate matter for the planets could not be poured out from an atmosphere whose mass was negligible. If the defect were merely quantitative, it might be remedied by a change in the terms of the theory, but it is qualitative as well. The earth is made up chiefly of heavy molecules. The material poured out at the point of the cone on the extreme outer border of the atmosphere or envelope must therefore, to fit the case, *contain a due proportion of heavy molecules*. This is specifically true of the earth and quite certainly also of the solid planets, and probably also of parts of the major planets.

A convective sun necessary.—Now, the only known way in which heavy molecules are lifted into the upper levels of great atmospheres or great gaseous bodies, and kept there, is by *convection* or some equivalent form of *turbulence*. But turbulent convection is the ulterior basis of the erupto-tidal sub-theory of the planetesimal hypothesis, for solar convection is assigned to solar radiation, which has existed as long as the sun has been a sun. As the radiation is great the convection is tumultuous and eruptive. The rotation of the sun divides the convectional mass into two hemispheres, and introduces special motions of its own which bring about conflicting actions in the equatorial zone from which the eruptions of that region, at least in part, spring. This is believed to remain true whatever may be the mode of transfer of internal heat and whatever accessory agencies may be involved in the circulatory and eruptive processes. The tidal forces of the passing star could not act tidally on the sun as though it were a passive body unaffected by solar turbulence, and it now appears that this convection was necessary to give even the tidal theory working qualities in respect to another vital matter. It appears, therefore, that at the very first step in working application, the tidal theory is driven back to the parent-form. The need of convective turbulence is made all the more imperative if the sun is assigned an expanded condition at the time of the star's passage. If the sun then had a radius of 21,000,000 kilometers, the dimension assigned by Jeffries, the tax on convection would be severe; if the radius was above 4,000,000,000 kilometers, as assigned by Jeans, the tax would be still more severe. Observation does not lend support to these ultra-dimensions at the working stage, for the outer parts of the giant stars are usually formed of light molecules.

The infelicity of the tidal theory is further emphasized by the claim of simple tidal outpour from a surface cone, for such a cone would inevitably be supplied mainly from the outer layer which would be most affected by tidal action. On the other hand, the parent-theory appeals to eruption which has its sources in the depths where heavy molecules are more

likely to abound. With such a showing at the very outset, there is a temptation to give the tidal theory the coup de grace right here and have done with it. But it would be poor stagecraft to kill off the Hamlet of the play so early in the first act. So let us lend the tidal theory enough convective turbulence from the tenets of the planetesimal hypothesis to keep it on the stage until later in the play. We will have to shut our eyes to the impossibility of *simple* tidal action on a tumultuous sun, or else imagine that the tumultuous factor makes no essential difference.

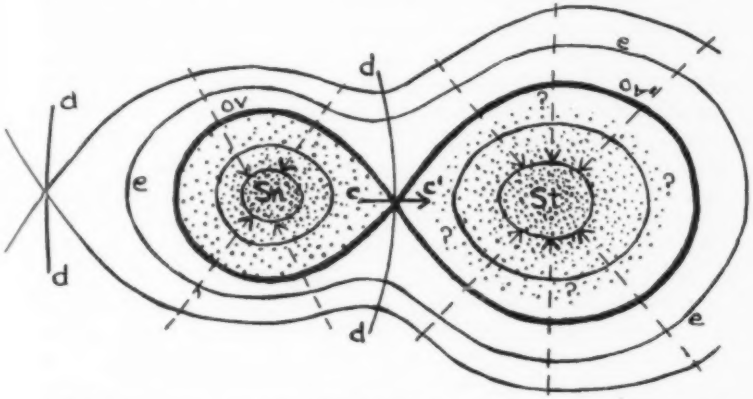


FIG. *A* (reviewer).—An extension and modification of Jeffries' Fig. 1, showing the sun and star, with added lines representing the boundary between the spheres of control of the star and sun, respectively, based on the equipotential lines. *Sn* = sun; *St* = star; dotted areas represent sun and star; equipotential lines as in Fig. 1 (author) but somewhat extended to give fuller view of star; *d*–*d* = boundary of spheres of control of sun and star; radial lines represent directions of dominant gravitation.

But if we are to go on with an amended theory for the sake of testing it in other respects, we need a new figure that presents a substantial convective sun, a real star, the spheres of control, and other concrete working features. To make it clear that the author is not responsible for this, let us call it Figure *A* (reviewer). For convenience, let us retain the equipotential lines of the author's Figure 1, though they need to be changed if they are to represent the configuration of the solar matter and not simply the instantaneous state of the sun-star gravities. Let us extend them a little to bring the star into fuller view. Let us add also lines to represent the boundary between the spheres of control of the star and sun, respectively, basing these on the equipotential lines. These

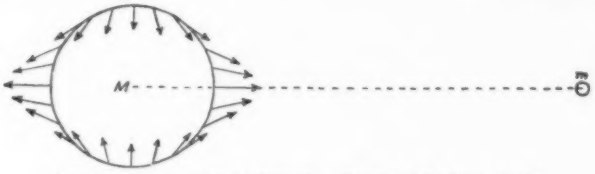
spheres of control were in process of shifting, just as the relative gravities of the two bodies were.

The relations of the solar outpour to the star.—Thus constructed, the figure brings vividly to the eye the critical fact that the supposed outpour not only is directed toward the center of the star as explicitly stated by the author but that it is from the start relatively near the surface of the star, and that *it immediately enters the sphere of control of the star.* As this control is stronger than that of the sun, by reason of the star's greater mass, *how is the outpour to escape from the star's control as it must do if it is to form the planets, for these of course must revolve within the sphere of control of the sun?* It is to be noted that the sphere of the star's dominance tends to envelop that of the sun, and this tendency increases as the star moves nearer to the sun. Here again the tidal theory runs upon a fatality if merely static or instantaneous conditions are adhered to. If there is any line of escape at all, it lies in the relative motions of the sun and the star. The dilemma is not frankly discussed, perhaps not clearly seen, but the context makes it clear that the star is supposed to move out of the way. But the question remains, Even if the star does, will the star's sphere of control move out of the way? We shall see later.

Correction for relative motion.—But the relative motions now brought in to escape a serious difficulty do not seem to have been taken into consideration in working out the lines of the basal configuration (Fig. 1) on which inferences about the outpour on only one side, and in other respects, were founded. To bring in these relative motions there is need for amending the basal configuration. It has already been noted that correction or replacement is required to fit the turbulent state of the solar body. To avoid misconception it is to be explained that this is corrective from the practical point of view but that in strictness it is correction by replacement, for the equipotential lines, on whose configuration the essentials of the theory are built, represent merely the *instantaneous* relations; *they do not represent the configuration of the two bodies in hyperbolic motion.* This latter is affected by all the motions to which the material is subject. Now, it is quite evident that if relative motion is to be brought into consideration to pull the ejected matter out of the control of the star, it must be taken into consideration as a factor in determining the configuration of the sun on which the main line of thought is made to rest. While the maximum motion is uncertain, because it involves unknown inherited motions, the minimum motion for the case in hand is determinable, *for a certain relative velocity is necessary to keep*

the two bodies from colliding. With reasonable postulates as to the radii of the two bodies, this will be found to be rather high motion.

Now high relative motion would seriously condition the development of the sharp point of the sun which is *assumed* to be a point of ejection, and bring into question the formation of any filament at all. If the relative velocity were infinite, it is clear that no cone or filament would be formed. The effects of various relative motions are of course too complicated to be followed out here, but the general trend of their effects may give us some intimation of the nature of the results. If merely the motions which the sun and star generate in one another by their approach be considered, they take the form of a revolution about their common center of gravity. This center is nearer the star than the sun. The centrifugal effect of the revolution will be greater on the *distal* than on the proximate side of the sun, and this will tend to give protuberance on that side, in accordance with the well-known deductions of standard tidal



Standard figure of tidal distortion (Darwin, Moulton, *et al.*)

analysis. This justifies the belief that if all the motions of the two bodies were brought into consideration the results would be identical with standard tidal deductions, and that such ultra-features as the excessively sharp cone and the special jet or filament would disappear. The standard concept is that of bulges on the proximate and distal sides, with a compress-band between them as in the accompanying figure in common use.

The tidal theory in action.—The crux of the whole matter comes when the assigned factors are put into action. For this, we turn to Figure 2, page 20 (here reproduced), which is offered to show the early stages of action under the tidal theory. The three ovate figures represent three successive positions of the tide-distorted sun. The oval outlines stand for the configuration represented by the heavy line in Figure 1, just now under consideration. From the sharp points of these three ovate figures outpours of planetary matter are indicated by dotted lines, as also the courses pursued by them. The ends of these courses are grouped to form what is called a "boomerang."

Now the ovate figures of the sun enable us to fix the positions of the passing star at the stages when the outpours started, for the relations of the sun and star were then critical and strictly necessary to the outpours, as stated by the author. With any other relationship, the postulated outpour would not take place. To show these positions, we have intro-

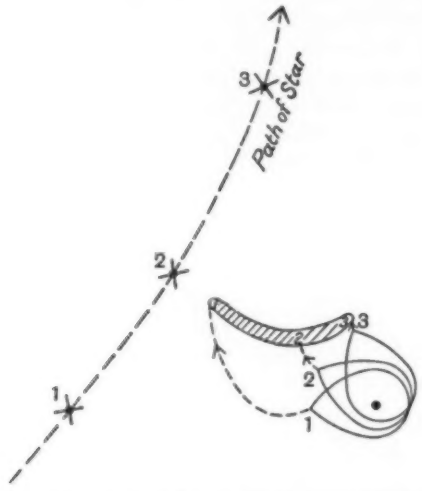


FIG. 2.—Diagram of the changes in the form of the solar envelope and the paths of portions of the ejected matter during the passage of the star. (Reproduced from Jeffries' *The Earth, Its Origin, History and Physical Constitution*, p. 20.) The three oval figures represent three successive positions of the sun; the ovals themselves represent the form of the sun at the critical stage shown by the heavy line in Fig. 1. The curved line at the left represents the assigned path of the star, the three points represented by crosses 1, 2, 3, the positions of the star at the instants when the jets or filaments 1, 2, 3 started from the point of the sun; the cross-lined figure shows the "boomerang"-like form of the ejection at a certain later stage close after ejection 3 had started.

duced Figure *B* (reviewer). To avoid obscuring the figure, only the stubs of the bounding lines between the spheres of control at each stage are represented, but the reader can easily project them. We have superposed these added features on the figure of the text for convenience of comparison. By connecting the three positions of the star, we get its course and also the directions in which it would draw the filaments at its successive positions.

The divergences of the new figure from the figure of the text are very striking: (1) the star's path is much nearer the sun; (2) it is concave *toward* the sun, not away from it; (3) the star and its sphere of control are seriously in the way of the paths assigned the filament; (4) the "boomerang" is put in an awkward position (but we need not worry about that, for a boomerang of some sort is quite sure to wriggle out of such a tangle as this); and (5) the embarrassing predicament of the fila-

FIG. *B* (reviewer).—Diagram superposed on Fig. 2, showing the positions of the passing star at the stages when the outpours started, and the necessary divergences from Jeffries' Fig. 2. The dotted ovals represent the successive positions of the star corresponding to those of the sun and the interference of these with the assigned projections of the filaments; only the stubs of the boundary lines of the spheres of control are represented.

ments is made obvious: (*a*) the danger that the filaments will be drawn directly into the star itself is even more obvious than before; (*b*) if the filament could escape the star itself, there seems no way of escape from the sphere of control of the star; and (*c*) if it could escape these perils, its course would necessarily be between the star and the sun, for these are the two bodies which are the sources of the attraction said to have formed it. If it could be supposed to go outside the star, both star and sun would draw backward upon it. Even if the sun be given a radius so great as

21,000,000 kilometers, the path of the star during the critical filament-generating stages would still lie inside the orbit of Mercury and the path of the filament between the star and the sun. There seems therefore no mechanism for projecting the filament 4,000,000,000 kilometers across the planetary field, while there is at hand a powerful agency for carrying the filament off with the star. Under these contingencies, almost the only course assignable to the filament is a curved path toward the center of gravity of the star, *an inrunning spiral*, if you please.

The further embarrassments of the filament.—If it is not a brutality to pursue the poor filament further, let us consider its postulated bunching, the bunches later to condense into planets. Something of the nature of a massing into a nucleus was necessary to actuate the aggregation of the widely stretched filament into planets. If the actual conditions of the planetary field could be ignored, and the filament be projected into an empty region outside the universe, no doubt the self-attraction of the parts of the filament and the wave-lengths of its pulsations might effect a bunching as postulated by Jeans. But the planetary field was by no means empty dynamically. It was permeated by stresses, actual or potential. The filament was ejected into these, and its own feeble stresses were brought into competition with much more powerful ones, to wit: (1) the whole field was stressed by the gravitation of the sun; (2) during the period of critical action, the whole field was stressed by the star's attraction also; (3) when the star passed away, it left the planetary matter under the influence of the planetary motion which it had generated in co-operation with the sun. The normal planetary motion in the innermost part of the planetary field is now eight times as great as the similar motion in the outermost part. If the filament could ever have been stretched across the planetary field, it would be under the further stretching influences of these planetary motions. Compared to these, its own self-attraction and pulsations were trivial. Let us put this to test of existing dynamic conditions. It is clear that the full-grown planets have stronger attractions than did any corresponding part of the stretched and stretching filament. The present spheres of control of the planets therefore represent concretely the maximum assembling power of the planetary matter. The spheres of control of all the planets, if arranged in a line, would cover less than 10 per cent of the distance between Mercury and Neptune, if we use the mean of Laplace's and of Moulton's computations, and make an allowance of 50 per cent for elongation in the direction of the planets. The bunching of the filament, as postulated by Jeans, seems therefore to have no adequate basis.

The postulated mode of formation of the satellites is as follows:

> Each nucleus would pass near the sun at its first perihelion after it was formed. . . . . A filament would then be produced by the planet, and would go through a process of development similar to that of the filament ejected by the sun. This is the mode of origin of the satellites suggested by Jeans [p. 33].

If this is true, the satellites should lie in the orbital planes of their respective primaries as closely as the planets lie, by hypothesis, in the plane of the passing star. The orbits of the satellites should form disks closely coinciding with the planetary planes. *But nearly all of the satellites revolve at considerable angles to the planes of the orbits of their primaries*, most of them at rather large angles. On the other hand, most of the satellites revolve nearly in the *equatorial* planes of their primaries, so far as these are known. Some relationship of the satellites to the rotation of the planets seems clearly indicated. The proposed theory appears therefore to be quite untenable.

"*The resisting medium.*"—The occasion for a resort to a "resisting medium" obviously arises from the neglect by the proponents of the tidal theory of the propulsive possibilities of the sun at the outset. The sun's great powers of propulsion, combined with light-pressure and the star's attraction from a distance, should have given rise to an orbital distribution of the planetary matter of moderately eccentric types only, whereas by neglecting the projective possibilities of the sun and trying to work out a theory on tidal pull alone, very close approaches of the star to the sun were unavoidable. As a result, the perihelia of the planetary nuclei were necessarily near the sun and their orbits were very eccentric—indeed, cometic in type. There followed the necessity of postulating some very effective means of transforming these highly eccentric orbits into the nearly circular orbits of the present planets. But, even so, the resort to "a resisting medium" puts the theory at a great disadvantage, for, though sources of resistance are well known and are in actual service, there is no recognized "resisting medium." The term "resisting medium" suggests something weird and pervasive. It throws an atmosphere of vagueness over even the known resistances and obscures the whole subject. Meteorites are sources of resistance but the resistance is individual and irregular; it is better treated specifically than vaguely as "a medium." The planets themselves offer resistance to bodies that encounter them, but one would scarcely think of them as constituting "a resisting medium." Planetesimals are sometimes sources of resistance and sometimes sources of acceleration. This diversity of function shows pointedly the inaccuracy of treating them as

"a resisting medium." The motions of the planetesimals and the planets are *concordant* with one another and their junctions are overtakes. Planetesimals may accelerate planetary motions, and they are somewhat more likely to do this than to lower them. It is chiefly the *swifter* atoms, molecules, and aggregates that separated from the nuclei when both were belched from the sun, as also at later stages. They are thus likely to carry more momentum relative to mass than the nuclei, and so to accelerate the latter when they joined them, for, as just noted, the conjunctions were *overtakes*, not head-on or broad-angle collisions. The treatment of the derivatives from the solar atmosphere which have vaulting flights, or take orbital courses, can only be intelligible by being discriminative. If they are dumped into a vague "resisting medium," confusion is the natural result. The occasion for these reflections will appear at once as we proceed to examine what our author says in respect to "the resisting medium" as he understands it:

> It has already been indicated that the matter ejected from the sun would not all be included in the planets and their satellites. Much of it would be lost on account of the inadequacy of the gravitative power of the distended nuclei to retain their lighter constituents, and the thinner parts of the filament would probably be unable to condense at all but would spread out at once. This lost material would be dispersed throughout the system, and would form the resisting medium. . . . . It would have the same origin as the planets and therefore would have been deflected transversely by the star, just as the planets were. Hence every part of it would have a direct revolution about the sun from its very beginning [p. 47].

This is a clear and unequivocal description of matter in the planetesimal state, that is minute matter in concurrent, planet-like orbits. It is further made clear in the context that normally each escaping molecule will take an independent orbit about the sun. They are therefore planetesimals in precisely the sense used in the planetesimal hypothesis. Indeed, such escape of molecules by reason of superior molecular activity is the type chosen by Chamberlin as the simplest of the several modes of planetesimal formation, and hence as best illustrating the subsequent career of planetesimals (*Journal of Geology*, Vol. XXVIII [1920], pp. 666–71). It thus appears, quite singularly, that the assigned resisting medium is no more nor less than the planetesimals derived from the filament and the planetary nuclei.

Now there is no question that the reunion of the separated orbital matter with the nuclei will tend toward the equalizing of their momenta and toward correspondingly intermediate orbits, but if the escaped molec-

ules, the planetesimals, on the average, carry the higher proportions of momentum, they would have an *accelerating* rather than a resisting effect on the nuclei.

Substitution of gaseous organization in place of planetesimal organization.—Clear and unequivocal as is the description of the formation of orbital or planetesimal matter, the author abruptly, and apparently unconsciously, substitutes the gaseous concept for the planetesimal concept and proceeds thence to treat this orbital matter as though it were gaseous matter. He says: "It is clear from its formation that it would be largely or entirely gaseous" (p. 47). The mental process back of this seems to be: The separated matter is largely molecular; therefore it is gaseous. But the molecules are sent off individually into planetary orbits. Individual molecules do not constitute a gas. Individual molecules are now regarded as elastico-rigid organizations. Next after atoms, they form the highest known type of such organization. Molecules become a gas only when they are *assembled* in the gaseous mode, the well-known to-and-fro collisional form of assemblage. The name is a matter of secondary importance, but an orbital organization should be treated according to the principles of orbital dynamics, while a gaseous organization should be treated according to collision-rebound dynamics. In the case in hand, orbital dynamics unquestionably obtained. The subsequent history of the orbital molecules should be worked out in accordance with the principles of orbital mechanics (see article in this *Journal* cited above). The gaseous organization is not only dynamically different from the orbital or planetesimal, but is *dynamically inferior*, and will necessarily give a lower grade of results dynamically considered. Molecules in orbits of the planetary type—that is, planetesimals—if free from interference, continue indefinitely in their orbits, just as planets do. Gaseous molecules are not normally thus self-sustaining; they tend constantly to fall toward some center of superior power. Out of this weakness and its collisional results spring the qualities of gaseous diffusion, viscosity, density, and temperature, which our author erroneously assigns to the orbital bodies so explicitly described. The context makes it perfectly clear that, at this point, the author's reasoning has slipped from the superior planetesimal to the inferior gaseous state, and that he rests his discussion thence onward on the substituted state. He immediately calls in the effects of "diffusion" and "viscosity," qualities of gases, but not, at least in the same sense, of bodies in planetary orbits. He soon enters upon mathematical treatment in which gaseous "density" and "temperature" are leading factors. The reader may find abundant confirmation of the

continued use of this substitution in all the subsequent chapters. It is not too much to say that the gaseous concept becomes from this point on the guiding idea. It is therefore not worth while to follow, in detail, the discussion farther. This is the parting of the ways.

Misinterpretations.—It is not strange that the substitution of gaseous for planetesimal dynamics should be attended by other misinterpretations. Some of these take on an amusing form. For example, orbital molecules (planetesimals, treated as gaseous) are put forward, as we have just seen in the chapter on the resisting medium, as an approved agency for changing nuclear comet-like orbits into nearly circular planetary orbits, while in the Appendix, where the planetesimal hypothesis is under view, the gathering-in of planetesimals has only the most trivial value, to wit:

> *Impossibility of Great Accretion.*—Perhaps the most serious divergence between the two theories is, however, in the nature of the postulated resisting medium. In the present work it is supposed to be a gas, probably chiefly hydrogen; in the Planetesimal Hypothesis it is supposed to be composed of particles that solidified during the condensation of the planets, but acquired velocities so great that gravity could not retain them. These would then revolve around the sun as independent bodies; they are the "planetesimals" that give the theory its name. It is supposed that they were afterwards largely swept up by the planets, and that their effect was to reduce the eccentricities of the planetary orbits to their present values. Now it is possible and indeed almost certain, that many such small solid particles were actually set in motion during the cooling of the planets, but there is a grave objection to supposing that they can have had any important effect on the orbits of the planets [p. 250.]

This is the climax of a comedy of substitutions. The planetesimal hypothesis pleads irresponsibility for any "postulated resisting medium." It offers a circularity-producing mechanism, but this consists of the union of masses in concurrent motions in such a way that the increases in the velocities of some are offset by decreases in the velocities of others, and the result is the canceling out of individual eccentricities. To illustrate, if some of the planetoids should join Mars, the latter would take on a larger orbit with greater potential energy, because the planetoids are exterior to Mars, and a new eccentricity, depending upon the circumstances of the union. No resisting medium other than the bodies themselves would be involved.

The existence of resistances from meteorites or other bodies moving in discordant orbits or having discordant factors, and from the krenal

and orbital derivatives from the sun's atmosphere, and their function in changing planetary, planetoidal, and planetesimal orbits in the direction of circularity, is of course recognized. That is a function of the planetary environment, and whatever these outside agencies can have done is not assigned to planetesimal-nuclear aggregation, otherwise the theory would overdo its job.

On the side of the tidal theory, we have just seen that the postulated resisting medium in reality consists of planetesimals, though held to be gaseous and here regarded as hydrogen, though theoretically all gases present in the filament or nuclei should have made their contributions. But whatever the physico-chemical constitution, they were orbital or planetesimal as factors in the celestial dynamics involved. So it appears that, when analyzed, the putative resisting medium of the tidal theory belongs to the same type as that of the theory from which it was derived. And why not? Previous to this stage, the tidal theory had taken over from the planetesimal hypothesis (1) the approach of a star, (2) its tidal action (partially), (3) an ejection of solar substance to form the planets, and (4) the drawing of the ejected matter into planetary orbits in the plane of the passing star; in short, about all the essentials of the case. It is weaker than the parent-theory to the extent of the neglected factors, particularly the neglect of the great potentialities of the sun as a projective agency and the neglect of the great mass-belches arising from its eruptivity, which gave origin to the nuclei and planetesimals. With qualifications of this sort the two are essentially alike, only the planetesimal hypothesis is very much broader—taking in all known factors and diligently searching for others— and very much more powerful and competent, and has withal been made as scrupulously concordant with nature as prolonged and persistent study could make it. It is therefore somewhat diverting when the obviously weaker is put forth as superior under cover of changes of phraseology and substitution of concepts.

It is also diverting to be told that the planetesimals which give name to the theory are "particles that solidified during the condensation of the planets." The main formation of planetesimals took place long before the planets were formed, and as a first step toward their formation, as stated very elaborately and explicitly in the standard expositions of the planetesimal hypothesis. With so many explicit definitions and so many quotable passages at command, it seems surprising that a nearer approach to the real concept has not been given in a work of this class. The following quotation was easily available:

After the smaller gas-bolts had been shot from their compressed state [in the sun] into the approximate vacuum of interstellar space, their competency to hold the more active molecules was distinctly limited, even in the case of the terrestrial planets. . . . . The light, active molecules that mingled in these smaller gas-bolts must probably, as they issued into open space, have been scattered . . . . by the force of their own collisional reactions, and must have entered on paths of their own under the direct control of the sun, but free from the control of the bolts with which they were shot forth. . . . . If so, they no longer constituted bodies of gas in the true kinetic sense. In following orbital paths about the sun, they had the dynamic qualities of little planets, that is, they were planetesimals. This name has been introduced to designate all such small bodies—whether atoms, molecules, or aggregates—as behave like minute planets. This is done to distinguish them from the constituents of gases . . . . that have different dynamic qualities [*The Origin of the Earth* (1916), pp. 138–39].

The extent of the accretion.—This citation is a part of a discussion respecting the proportions of the gas-bolts which might go into the nuclei, on the one hand, and into the planetesimal state, on the other, in other words, the basis of later growth by accretion. It was stated in one of the earliest presentations of the planetesimal hypothesis to the studious public that it would be the working assumption that "the nuclei constituted only a small portion of the mass of the grown planets" (*Geology*, Chamberlin and Salisbury, Vol. II [1905], p. 64). This later study developed additional reasons for the conclusion that the masses of the nuclei were relatively small and those of the planetesimals relatively large. The growth of the earth by accretion may easily have been tenfold. There appear no cogent reasons why accretion may not have been much greater than this. Reasons have been entertained by the protagonists of the theory and have been offered by others why accretion had limits in its own processes, but they have not stood examination. There were of course limits in the amount of matter supplied, but given the material, growth seems possible to degrees of almost any order.

Volatilization.—The author endeavors to build a serious objection on the basis of planetesimal collision and volatilization, citing the plunge of *meteorites* into the *atmosphere*, which betrays the persistency of the confusion between antagonistic motions as those of meteorites in the orbital class and gases in the collisional class. The conjunctions of the planetesimals, as said repeatedly before, are essentially concurrent and hence overtakes, and relatively mild. But if volatilization takes place, as it probably does at times, the effect would be merely to create more and

minuter planetesimals and start a new series of aggregations. The matter is not "lost." At most the process is merely delayed.

One other quotation must suffice for the "objections" to the parent-theory:

> The authors of the Planetesimal Theory believe that the planets would cool principally by adiabatic expansion, although it is shown here that at any rate the larger ones would cool principally by radiation from the surface [p. 250].

Prompted by this statement, the reviewer has canvassed the authoritative literature of the planetesimal hypothesis and finds the common expression used in reference to the genetic stages to be the couplet "expansion and radiation." One would think that cooling by "expansion and radiation" would be about the right expression for the development of a part of the sun into a filament reaching 4,000,000,000 kilometers across the planetary field and taking on additional stretching because of the different rates of motion of planetary matter at different distances from the sun.

The cooling of the planets was a postgenetic matter that does not concern us here.

An earlier contingency.—It will be recalled that earlier in this comedy of substitutions we thought best not to touch the vital spot that would have spoiled the play. But if anyone who has a feeling for nature and reality chooses to apply the principles of Roche disintegration and the famous Roche limit (2.44 of the radius of the *major* body, the star) to the critical stage of approach of sun and star (2.78 times the diameter of the *minor* body, the sun), taking into account the radiation pressure, the centrifugal components of rotation and of internal motions, and the potential explosiveness of the sun, he may see where the Hamlet of the play really took his expansive and spectacular exit from the stage.

Application of the gaseous interpretation.—It has been seen that, according to our author, the genetic processes of the tidal theory lead to an orbital state of the ejected solar matter, both in the form of nuclei and of minute orbital matter, the lines being closely similar to those previously blazed by the planetesimal hypothesis, but that this matter was, notwithstanding, interpreted as being gaseous. As a result, deductions from a supposed gaseous state permeate the later chapters of the book. There is therefore in these further discussions little that differs from the deductions long ago drawn from the older gaseous or quasi-gaseous hypotheses. As our space is already overtaxed, we must restrict further comment to a few of the more striking features.

The competency of cooling to account for earth shrinkage is among these. With the disclosure that radioactivity is apparently competent to generate heat as fast or faster than it is being radiated from the earth surface, efforts to explain the deformation of the earth by cooling have been almost entirely abandoned, and it creates a little surprise that they should be resumed here. The notable feature in the author's treatment is the wholly inadequate estimate of the deformation to be explained. The estimates cited relate to little more than the deformations of the last half of post-Cambrian time. By far the largest amount of deformation occurred in pre-Cambrian time. Probably the portion claimed to be explained does not represent more than 10 or 15 per cent of the whole diastrophism.

In the treatment of modern tidal problems there is no reference to the remarkable work of Michelson, Gale, and Moulton, and almost equal neglect of the co-ordinated contributions of five authors in *Carnegie Publication Number 107*. There is no intimation that an inertia tide must almost certainly spring from the rocking of the great water-basins by the earth-tide. There is no warning that a thoroughgoing reconstruction of tidal interpretations is a prerequisite to building any safe superstructure on tidal theory.

In the treatment of seismic effects as evidence of the state of the earth's interior, there is neglect to take fully into account the effects of the increase of density with depth. It is standard doctrine that density damps the seismic waves. The true elastic state of the interior can therefore be obtained only by carefully correcting the observations for the changes of density as depth increases. While the precise distribution of density in the interior is an open question, it is, in a general way, indicated by astronomical data. Roche long ago prepared a formula to satisfy these data as nearly as practicable. All attempts at the interpretation of seismic data should at least frankly recognize the necessity for this correction and apply the formula of Roche or some other.

The book offers a stimulating study to one interested in the building of theories of the origin of our planetary system, and in the application of such theories to our great earth-problems. Our examination has revealed a surprising number of neglected factors. Such neglect seems, indeed, the most characteristic feature of the book and of the tidal theory it advocates. This is in keeping with its initial divergence from the parent-theory by the neglect of the convective-eruptive potentialities of the sun.

T. C. C.

INDEX TO VOLUME XXXII

PAGE

Adams, Leason H. A Physical Source of Heat in Springs . . 191

Allan, John A., and Rutherford, Ralph L. Fourth Annual Report on the Mineral Resources of Alberta, 1922. Part I. Saunders Creek and Nordegg Coal Basins, Alberta, Canada. Review by A. H. B. . 264

Allen, E. T., and Day, Arthur L. The Source of the Heat and the Source of the Water in the Hot Springs of the Lassen National Park . . 178

Andrews, E. C. The Geology of the Broken Hill District. Review by E. S. B. 638

Anleitung zur mikroskopischen Bestimmung und Untersuchung von Erzen Aufbereitungsprodukten besonders im auffallenden Licht. By H. Schneiderhöhn. Petrological review by Albert Johannsen . 445

Athy, L. F. Review of Marble Deposits of East Tennessee . . . 640

Barnett, Leon H. The Chemistry of the Earth's Core 615

Basalts, Some Inclusions in. By Stephen Richarz 685

Bastin, E. S. Review of Gypsum: Its Occurrence, Origin, Technology, and Uses. By Frank A. Wilder 347

———. Review of India's Mineral Wealth. By J. Coggin Brown . 637

———. Review of Mining Review for the Half-Year Ended December 31, 1922, No. 37. By Lionel C. E. Gee (Compiler) 176

———. Review of The Geology of the Broken Hill District. By E. C. Andrews 638

Bau und Entstehung der Alpen. By Leopold Kober. Review by R. T. C. 168

Bell, A. H. Review of Fourth Annual Report on the Mineral Resources of Alberta, 1922. Part I. Saunders Creek and Nordegg Coal Basins, Alberta, Canada. By John A. Allan and Ralph L. Rutherford 264

———. Review of Geology of a Portion of the Badlands. By Freeman Ward 351

———. Review of Origin of the Tectite Sculpture and Some Consequences. By R. W. Van Der Veen 638

———. Review of Palaeozoic and Mesozoic Seas in Australasia. By W. N. Benson 448

———. Review of Report of the State Geologist of Vermont, 1921–1922. By George H. Perkins 447

———. Review of The Devonian of Missouri. By E. B. Branson . 638

———. Review of The Geology of Corrour and the Moor of Rannoch. By Hinxman, Carruthers, MacGregor, Clough, Thomas, and Read 544

PAGE

Bell, A. H. Review of The Geology of the Country round Banff, Huntly, and Turriff. By H. H. Read 448
———. Review of The Occurrence of Ground Water in the United States. By O. E. Meinzer 447
———. Review of West Virginia Geological Survey: Tucker County. By David B. Reger 350
Benson, W. N. Palaeozoic and Mesozoic Seas in Australasia. Review by A. H. B. 448
Berry, Edward W. Fossil Plants and Unios in the Red Beds of Wyoming 488
Black Shale of Southwestern Virginia, The. By George W. Stose. . 311
Boeke, H. E., and Eitel, W. Grundlagen der physikalischchemischen Petrographie. Review by Albert Johannsen 337
Book notices 176, 640
Branner, John Casper. By James Perrin Smith 240
Branson, E. B. The Devonian of Missouri. Review by A. H. B. . 638
Brauns, Reinhard. Die Mineralien der Niederrheinischen Vulkangebiete mit besonderer Berücksichtigung ihrer Bildung und Umbildung. Review by Albert Johannsen 337
Breaking of Waves in Shallow Water, The. By Paul MacClintock . 407
Bretz, J Harlen. The Dalles Type of River Channel 139
British Antarctic Expedition, 1910–1913, The Physiography of the McMurdo Sound and Granite Harbor Region. By Griffith Taylor. Review by William Herbert Hobbs 636
Brown, J. Coggin. India's Mineral Wealth. Review by E. S. B. . 637
Brown, John S. The Hot Springs of the Republic of Haiti . . . 384
Bryan, Kirk. The Hot Springs of Arkansas 449
Bucher, Walter H. The Pattern of the Earth's Mobile Belts . . 265
Buddington, A. F. Review of Temperature-Viscosity Relations in the Ternary System, $CaO—Al_2O_3—SiO_2$. By Alexander L. Feild and P. H. Royster 174
Bushveld Igneous Complex, Transvaal, Structural Relations of. By Reginald A. Daly and Gustaaf A. F. Molengraaff 1

Chamberlin, R. T. Editorial 442
———. Review of A Catalogue of Geological Maps of South America. By Henry B. Sullivan 262
———. Review of Bau und Entstehung der Alpen. By Leopold Kober 168
———. Review of Die Grundlagen der Alpiner Tektonik. By F. Heritsch 172
———. Review of Geologic Structures. By Bailey Willis . . . 344
———. Review of Geologie der Schweiz. By Albert Heim . . . 85
———. Review of Transactions of the Institute of Economic Mineralogy and Petrography 639
———. The Significance of the Framework of the Continents . . 545

PAGE

Chamberlin, T. C. Review of The Earth, Its Origin, History, and Physical Constitution. By Harold Jeffries 696
———. Review of The Planetesimal Hypothesis and the Solar System. By Harry Fielding Reid 242
Chemistry of the Earth's Core, The. By Leon H. Barnett . . . 615
Climatic Changes. By Ellsworth Huntington and Stephen Sargent Visher. Review by Hervey W. Shimer 543
Coal Resources of the Raton Coal Field, New Mexico. By W. T. Lee. Review by D. J. F. 639
Coal Seams, The Relation of Concretions to. By José Maria Feliciano 230
Cobble of Peculiar Shape, Note on a. By Chester K. Wentworth . 524
Concretions, The Relation of, to Coal Seams. By José Maria Feliciano 230
Correlation of Huronian and Grenville Rocks. By Terence T. Quirke 316
Correlation of the Lower Allegheny–Pottsville Section in Western Pennsylvania, The. By B. Coleman Renick 64
Crystallization, Relation of, to the Water Content and Vapor Pressure of Water in a Cooling Magma. By George W. Morey . . . 291
Crystallography, The Teaching of. Studies for Students. By D. J. Fisher 529

Dalles Type of River Channel, The. By J Harlen Bretz . . . 139
Daly, Reginald A., and Molengraaff, Gustaaf A. F. Structural Relations of the Bushveld Igneous Complex, Transvaal 1
Day, Arthur L. Hot Springs and Fumaroles of "The Geysers" Region, California 459
Day, Arthur L., and Allen, E. T. The Source of the Heat and the Source of the Water in the Hot Springs of the Lassen National Park . . 178
DeLapparent, Jacques. Leçons de Pétrographie. Review by Albert Johannsen 339
Determination of $2V$ in Sections Perpendicular to an Optic Axis, The. By T. C. Phemister 400
Devonian of Missouri, The. By E. B. Branson. Review by A. H. B. 638
Discussion of the Papers Presented in the Symposium on Hot Springs, Notes on the. By Robert B. Sosman : 464
Dolmage, V. Post-Pleistocene Volcanics of the British Columbia Coast 36

Earth, The, Its Origin, History, and Physical Constitution. By Harold Jeffries. Review by T. C. Chamberlin 696
Earth's Core, The Chemistry of the. By Leon H. Barnett . . . 615
Earth's Mobile Belts, The Pattern of the. By Walter H. Bucher . . 265
Economic Mineralogy and Petrography, Transactions of the Institute of. Review by R. T. C. 639
Editorial. By R. T. C. 442
Editorial: Proposed Oceanographic Research by the Navy. By David White 690

PAGE

Elementary Crystallography. By J. W. Evans and G. M. Davies. Review by D. J. F. 350
Elemente der Gesteinlehre. By H. Rosenbusch. Review by Albert Johannsen 443
Evans, J. W., and Davies, G. M. Elementary Crystallography. Review by D. J. F. 350

Fault, The Osburn, Idaho. By Joseph B. Umpleby. 601
Faulting South of Billings, Montana. By Gail F. Moulton . . . 511
Feild, Alexander L., and Royster, P. H. Temperature-Viscosity Relations in the Ternary System, $CaO—Al_2O_3—SiO_2$. Review by A. F. Buddington 174
Feliciano, José Maria. The Relation of Concretions to Coal Seams . 230
Fisher, D. J. Review of Coal Resources of the Raton Coal Field, New Mexico. By W. T. Lee 639
———. Review of Elementary Crystallography. By J. W. Evans and G. M. Davies 350
———. Studies for Students. The Teaching of Crystallography. . 529
Flint, Richard Foster. Studies for Students: A Brief View of Rocky Mountain Structure 410
Footprints in Pennsylvanian Sandstones of Colorado. By Junius Henderson 226
Fossil Plants and Unios in the Red Beds of Wyoming. By Edward W. Berry 488
Fossils, Marine Invertebrate, as Horizon Markers in the Pennsylvanian Rocks of Illinois. By T. E. Savage 575
Framework of the Continents, The Significance of the. By Rollin T. Chamberlin 545
Freshfield Glacier, Canadian Rockies, Observations on the. By Howard Palmer 432
Fuller, Margaret Bradley. General Features of Pre-Cambrian Structure along the Big Thompson River in Colorado. 49

Gee, Lionel C. E. (Compiler). Mining Review for the Half-Year Ended December 31, 1922, No. 37. Review by E. S. B. 176
General Features of Pre-Cambrian Structure along the Big Thompson River in Colorado. By Margaret Bradley Fuller 49
Geochemical Relations of Ground Water and Associated Natural Gas in the Lance Formation, Montana, Some. By B. Coleman Renick 668
Geologic Structures. By Bailey Willis. Review by R. T. C. . . . 344
Geological Maps of South America, A Catalogue of. By Henry B. Sullivan. Review by R. T. C. 262
Geologie der Schweiz. By Albert Heim. Review by R. T. C. . . . 85

PAGE

Geology of a Portion of the Badlands. By Freeman Ward. Review by A. H. B. 351

Geology of Corrour and the Moor of Rannoch, The. By Hinxman, Carruthers, MacGregor, Clough, Thomas, and Read. Review by A. H. B. 544

Geology of the Broken Hill District, The. By E. C. Andrews. Review by E. S. B. 638

Geology of the Country round Banff, Huntly, and Turriff, The. By H. H. Read. Review by A. H. B. 448

George, William O. The Relation of the Physical Properties of Natural Glasses to Their Chemical Composition 353

Gesteins- und Mineralprovinzen. Band I. By Niggli and Beger. Einführung. Chemismus der Eruptivgesteine insbesondere der Lamprophyre. By Paul Niggli. Review by Albert Johannsen 339

Granite and Gabbro Intrusions, The Contrast in the Effect of, on the Ely Greenstone. By G. M. Schwartz. 89

Ground Water, The Occurrence of, in the United States. By O. E. Meinzer. Review by A. H. B. 447

Ground Water and Associated Natural Gas in the Lance formation, Montana, Some Geochemical Relations of. By B. Coleman Renick 668

Grundlagen der Alpiner Tektonik, Die. By F. Heritsch. Review by R. T. C. 172

Grundlagen der physikalisch-chemischen Petrographie. By H. E. Boeke and W. Eitel. Review by Albert Johannsen 337

Gypsum: Its Occurrence, Origin, Technology, and Uses. By Frank A. Wilder. Review by E. S. B. 347

Heim, Albert, Geologie der Schweiz. Review by R. T. C. 85

Henderson, Junius. Footprints in Pennsylvanian Sandstones of Colorado 226

Heritsch, F. Die Grundlagen der Alpiner Tektonik. Review by R. T. C. 172

Hinxman *et al.* The Geology of Corrour and the Moor of Rannoch. Review by A. H. B. 544

Hobbs, William Herbert. Review of British Antarctic Expedition, 1910–1913, The Physiography of the McMurdo Sound and Granite Harbor Region. By Griffith Taylor 636

Hot Springs and Fumaroles of "The Geysers" Region, California. By Arthur L. Day 459

Hot Springs of Arkansas, The. By Kirk Bryan 449

Hot Springs of Iceland, The. By F. E. Wright 462

Hot Springs of the Lassen National Park, The Source of the Heat and the Source of the Water in the. By Arthur L. Day and E. T. Allen . 178

Hot Springs of the Republic of Haiti, The. By John S. Brown . . 384

PAGE
Hot Springs of the Valley of Ten Thousand Smokes. By E. G. Zies . 303
Hot Springs, The Temperatures of, and the Sources of Their Heat and Water Supply. By the Section of Volcanology and the Section of Geophysical Chemistry of the American Geophysical Union. A Symposium and Discussion 177, 291, 373, 449
Huntington, Ellsworth, and Visher, Stephen Sargent. Climatic Changes. Review by Hervey W. Shimer 543
Huronian and Grenville Rocks, Correlation of. By Terence T. Quirke 316

Inclusions in Basalts, Some. By Stephen Richarz 685
India's Mineral Wealth. By J. Coggin Brown. Review by E. S. B. . 637
Institute of Economic Mineralogy and Petrography, Transactions of the. Review by R. T. C. 639
Intrenched and Incised Meanders of Some Streams on the Northern Slope of the Ozark Plateau in Missouri. By W. A. Tarr . . 583

Jeffries, Harold. The Earth, Its Origin, History, and Physical Constitution. Review by T. C. Chamberlin 696
Johannsen, Albert. Petrological Abstracts and Reviews . . 337, 443
Johannsen, Albert, and Phemister, T. C. A New Method for Measuring the Optic Axial Angle of Minerals 81

Kober, Leopold. Bau und Entstehung der Alpen. Review by R. T. C. 168

Lancaster Gap Mine, Pennsylvania, A Note on the. By T. C. Phemister 498
Lance Formation, Montana, Some Geochemical Relations of Ground Water and Associated Natural Gas in the. By B. Coleman Renick 668
Leçons de Pétrographie. By Jacques de Lapparent. Review by Albert Johannsen 339
Lee, W. T. Coal Resources of the Raton Coal Field, New Mexico. Review by D. J. F. 639
Lehrbuch der Geologie: I. Teil, Allgemeine Geologie. By Professor Dr. F. X. Schaffer. Review by A. O. Woodford 88
Lehrbuch der Geologie, II. Teil: Grundzüge der historischen Geologie. By F. X. Schaffer. Review by A. O. Woodford 176
Lower Allegheny–Pottsville Section in Western Pennsylvania, The Correlation of the. By B. Coleman Renick 64
MacClintock, Paul. The Breaking of Waves in Shallow Water . . 407
Mansfield, George Rogers. Tertiary Planation in Idaho . . . 472
Marble Deposits of East Tennessee. Review by L. F. A. . . . 640
Marine Invertebrate Fossils as Horizon Markers in the Pennsylvanian Rocks of Illinois. By T. E. Savage 575
Meanders, Intrenched and Incised, of Some Streams on the Northern Slope of the Ozark Plateau in Missouri. By W. A. Tarr . . 583
Measuring the Optic Axial Angle of Minerals, A New Method for. By Albert Johannsen and T. C. Phemister 81

PAGE

Meinzer, Oscar E. Origin of the Thermal Springs of Nevada, Utah, and Southern Idaho 295
———. The Occurrence of Ground Water in the United States. Review by A. H. B. 447
Meland, Norman, and Reed, R. D. The Verden Sandstone . . . 150
Mineral Resources of Alberta, Fourth Annual Report on the, 1922. Part I. Saunders Creek and Nordegg Coal Basins, Alberta, Canada. By John A. Allan and Ralph L. Rutherford. Review by A. H. B. 264
Mineralien der Niederrheinischen Vulkangebiete mit besonderer Berucksichtigung ihrer Bildung und Umbildung, Die. By Reinhard Brauns. Review by Albert Johannsen 337
Mining Review for the Half-Year Ended December 31, 1922, No. 37. By Lionel C. E. Gee (Compiler). Review by S. E. B. . . . 176
Molengraaff, Gustaaf A. F., and Daly, Reginald A. Structural Relations of the Bushveld Igneous Complex, Transvaal 1
Moodie, Roy L. Paleopathology. An Introduction to the Study of Ancient Evidences of Disease. Review by A. S. Romer . . 262
Moraines of the St. Lawrence Valley. By Frank B. Taylor . . . 641
Morey, George W. Relation of Crystallization to the Water Content and Vapor Pressure of Water in a Cooling Magma 291
Moulton, Gail F. Faulting South of Billings, Montana 511

Natural Glasses, The Relation of the Physical Properties of, to Their Chemical Composition. By William O. George 353
Niggli and Beger. Gesteins- und Mineralprovinzen. Band I. Einführung. Chemismus der Eruptivgesteine insbesondere der Lamprophyre. Review by Albert Johannsen 339

Oceanographic Research by the Navy, Proposed. Editorial by David White 690
Optic Axial Angle of Minerals, A New Method for Measuring the. By Albert Johannsen and T. C. Phemister 81
Optical Mineralogy, Elements of. By N. H. and A. N. Winchell. Review by Albert Johannsen 446
Osburn Fault, Idaho, The. By Joseph B. Umpleby 601

Paleopathology. An Introduction to the Study of Ancient Evidences of Disease. By Roy L. Moodie. Review by A. S. Romer . . . 262
Palaeozoic and Mesozoic Seas in Australasia. By W. N. Benson. Review by A. H. B. 448
Palmer, Howard. Observations on the Freshfield Glacier, Canadian Rockies 432
Pattern of the Earth's Mobile Belts, The. By Walter H. Bucher . . 265
Pennsylvanian Sandstones of Colorado, Footprints in. By Junius Henderson 226

PAGE

Perkins, George H. Report of the State Geologist of Vermont, 1921–1922. Review by A. H. B. 447
Petrological Abstracts and Reviews. By Albert Johannsen . . 337, 443
Phemister, T. C., and Johannsen, Albert. A New Method for Measuring the Optic Axial Angle of Minerals. 81
Phemister, T. C. A Note on the Lancaster Gap Mine, Pennsylvania . 498
———. The Determination of $2V$ in Sections Perpendicular to an Optic Axis 400
Physical Properties of Natural Glasses, The Relation of the, to Their Chemical Composition. By William O. George 353
Physical Source of Heat in Springs, A. By Leason H. Adams . . 191
Planetesimal Hypothesis and the Solar System, The. By Harry Fielding Reid. Review by T. C. C. 242
Porto Rico and the Virgin Islands, Scientific Survey of, Volume II, Part I, The Geology of the Lares District, Porto Rico. By Bela Hubbard. Book notice 176
Post-Pleistocene Volcanics of the British Columbia Coast. By V. Dolmage 36
Pre-Cambrian Structure along the Big Thompson River in Colorado, General Features of. By Margaret Bradley Fuller 49

Quirke, Terence T. Correlation of Huronian and Grenville Rocks . 316

Read, H. H. The Geology of the Country round Banff, Huntly, and Turriff. Review by A. H. B. 448
Red Beds of Wyoming, Fossil Plants and Unios in the. By Edward W. Berry 488
Reed, R. D., and Meland, Norman. The Verden Sandstone . . . 150
Reger, David B. West Virginia Geological Survey: Tucker County. Review by A. H. B. 350
Reid, Harry Fielding. The Planetesimal Hypothesis and the Solar System. Review by T. C. C. 242
Renick, B. Coleman. Some Geochemical Relations of Ground Water and Associated Natural Gas in the Lance Formation, Montana . 668
———. The Correlation of the Lower Allegheny–Pottsville Section in Western Pennsylvania 64
Reusch, Hans. By Johan H. L. Vogt 336
Reviews 85, 168, 242, 344, 447, 543, 636, 696
Richarz, Stephen. Some Inclusions in Basalts 685
Rocky Mountain Structure, A Brief View of. Studies for Students. By Richard Foster Flint 410
Romer, A. S. Review of Paleopathology. An Introduction to the Study of Ancient Evidences of Disease. By Roy L. Moodie . . 262
Rosenbusch, H. Elemente der Gesteinslehre. Review by Albert Johannsen 443

PAGE
St. Lawrence Valley, Moraines of the. By Frank B. Taylor . . . 641
Savage, T. E. Marine Invertebrate Fossils as Horizon Markers in the Pennsylvanian Rocks of Illinois 575
Schaffer, Professor Dr. F. X. Lehrbuch der Geologie: I. Teil, Allgemeine Geologie. Review by A. O. Woodford 88
———. Lehrbuch der Geologie, II. Teil: Grundzüge der historischen Geologie. Review by A. O. Woodford 176
Schneiderhöhn, H. Anleitung zur mikroskopischen Bestimmung und Untersuchung von Erzen und Aufbereitungsprodukten besonders im auffallenden Licht. Review by Albert Johannsen . . . 445
Schwartz, G. M. The Contrast in the Effect of Granite and Gabbro Intrusions on the Ely Greenstone 89
Shimer, Hervey W. Review of Climatic Changes. By Ellsworth Huntington and Stephen Sargent Visher 543
Significance of the Framework of the Continents, The. By Rollin T. Chamberlin 545
Smith, James Perrin. John Casper Branner 240
Solfatara of Sousaki (Greece), A Recent Eruption at Methana (Greece), and Recent Maccalube at Vulcano, Notes on the. By Henry S. Washington 460
Sosman, Robert B. General Summary of the Symposium on Hot Springs 468
———. Notes on the Discussion of the Papers Presented in the Symposium on Hot Springs 464
Source of the Heat and the Source of the Water in the Hot Springs of the Lassen National Park, The. By Arthur L. Day and E. T. Allen 178
Springs, A Physical Source of Heat in. By Leason H. Adams . . 191
Springs and Geysers in Yellowstone National Park, Temperatures in Some. By C. E. Van Orstrand 194
Stose, George W. The Black Shale of Southwestern Virginia . . 311
Structural Relations of the Bushveld Igneous Complex, Transvaal. By Reginald A. Daly and Gustaaf A. F. Molengraaff 1
Studies for Students: A Brief View of Rocky Mountain Structure. By Richard Foster Flint 410
———. The Teaching of Crystallography. By D. J. Fisher . . 529
Sullivan, Henry B. A Catalogue of Geological Maps of South America. Review by R. T. C. 262
Symposium on Hot Springs, General Summary of the. By Robert B. Sosman 468
Symposium on Hot Springs, Notes on the Discussion of the Papers Presented in the. By Robert B. Sosman 464

Tarr, W. A. Intrenched and Incised Meanders of Some Streams on the Northern Slope of the Ozark Plateau in Missouri 583
Taylor, Frank B. Moraines of the St. Lawrence Valley 641

PAGE

Taylor, Griffith. British Antarctic Expedition, 1910–1913, The Physiography of the McMurdo Sound and Granite Harbor Region. Review by William Herbert Hobbs 636
Tectite Sculpture, Origin of the, and Some Consequences. By R. W. Van Der Veen. Review by A. H. B. 638
Temperature-Viscosity Relations in the Ternary System, CaO—Al_2O_3—SiO_2. By Alexander L. Feild and P. H. Royster. Review by A. F. Buddington 174
Temperatures in Some Springs and Geysers in Yellowstone National Park. By C. E. Van Orstrand 194
Tertiary Planation in Idaho. By George Rogers Mansfield . . . 472
Thermal Springs of Nevada, Utah, and Southern Idaho, Origin of the. By Oscar E. Meinzer 295
Thermal Springs of the Southeast Atlantic States. By Thomas L. Watson 373

Umpleby, Joseph B. The Osburn Fault, Idaho 601

Valley of Ten Thousand Smokes, Hot Springs of the. By E. G. Zies . 303
Van Der Veen, R. W. Origin of the Tectite Sculpture and Some Consequences. Review by A. H. B. 638
Van Orstrand, C. E. Temperatures in Some Springs and Geysers in Yellowstone National Park 194
Verden Sandstone, The. By R. D. Reed and Norman Meland . . 150
Vermont, Report of the State Geologist of, 1921–1922. By George H. Perkins. Review by A. H. B. 447
Vogt, Johan H. L. Hans Reusch 336
Volcanics of the British Columbia Coast, Post-Pleistocene. By V. Dolmage 36

Ward, Freeman. Geology of a Portion of the Badlands. Review by A. H. B. 351
Washington, Henry S. Notes on the Solfatara of Sousaki (Greece), A Recent Eruption at Methana (Greece), and Recent Maccalube at Vulcano 460
Watson, Thomas L. Thermal Springs of the Southeast Atlantic States 373
Waves, The Breaking of, in Shallow Water. By Paul MacClintock . 407
Wentworth, Chester K. Note on a Cobble of Peculiar Shape . . 524
West Virginia Geological Survey: Tucker County. By David B. Reger. Review by A. H. B. 350
White, David. Editorial: Proposed Oceanographic Research by the Navy 690
Wilder, Frank A. Gypsum: Its Occurrence, Origin, Technology, and Uses. Review by E. S. B. 347
Willis, Bailey. Geologic Structures. Review by R. T. C. 344

PAGE

Winchell, N. H. and A. N. Elements of Optical Mineralogy. Review by Albert Johannsen 446

Woodford, A. O. Review of Lehrbuch der Geologie: I. Teil, Allgemeine Geologie. By Professor Dr. F. X. Schaffer. 88

———. Review of Lehrbuch der Geologie, II. Teil: Grundzüge der historischen Geologie. By F. X. Schaffer 176

Wright, F. E. The Hot Springs of Iceland 462

Zies, E. G. Hot Springs of the Valley of Ten Thousand Smokes . . 303

© 11299 10